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13. ABSTRACT (Maximum 200 words) Environmental issues are an integral part of new systems acquisitions, from the simplest product to the more complex systems. This project is a part of the effort to understand the product variables for new systems and the methods for environmental improvement. The first system studied, in this joint US. Swedish project, is a PFHE shell grenade. We have begun by improving the techniques for determining the chemical emissions and energy requirements of the components of the PFHE shell. These components are weighting factors for making trade-offs of alternative materials and chemicals for such munitions. The shell life cycle was subdivided into eight subsystems, five of which are related to manufacturing. Since many munitions are not used in training or war, these manufacturing subsystems were discovered to be of significant importance. Our effort in this reporting period has been to develop the life cycle inventory of several chemicals not currently in the Swedish database. These were, di n-amyl phthalic acid ester, ammonium nitrate, trinitrotoluene, silver azide, and lead azide. The next step is to understand the relative environmental impact of the materials and chemicals architecture of this munition in relation to the overall product life cycle.

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Joakim Hägvall, Elisabeth Hochschorner, Göran Finnveden, Michael Overcash, Evan Griffing

Life Cycle Assessment of a PFHE Shell Grenade

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Life Cycle Assessment of a PFHE Shell Grenade

Abstract (not more than 200 words)

The environmental constraint on all activities in society increases. Today there is a growing understanding of the need to minimize the environmental impacts and the military defence can not be an exception. So far, most of the work in this field has been focused on the direct environmental impact from the energetic materials in the munition. There has been a very small amount of work on the life cycle aspects concerning military materiel.

This report describes a two year project, funded by the Swedish Armed Forces, with the purpose of performing life cycle assessments of munitions. As a case study, grenades for the Swedish combat vehicle 90 were chosen.

The results from this study show that the most environmental severe process is the use of the grenade in a warlike situation. It also shows that the use of metals and non renewable energy sources have a large impact on the life cycle.

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Abstract
This report presents the results from an Environmental Life Cycle Assessment of ammunition, a 40 mm grenade used by both sea and land weapons constructed with heavy metal alloyed balls. Two scenarios are studied, one in which the grenades are used in a war-like situation and one in which 95 % of the grenades are stored and then demilitarised and different materials are recycled as much as possible and 5 % of the grenades are used in practise. The war scenario includes impacts from emissions when the grenades explode, but not direct impacts from the explosion on humans, society or environment. The goals of the study are to identify aspect of the life cycle which have the largest impact on the environment, suggest improvement possibilities for the life cycle of the grenade, to make a comparison between different approaches for waste management of the ammunition and to provide a demonstration case about doing an LCA on military material.

The results clearly indicate the large difference between using the grenades in a war-like situation and the demilitarisation and recycling of materials. The results also indicate the advantages of recycling of materials in the grenades as a waste management strategy. The following improvement strategies are suggested: Change the shell in the grenade, decrease the use in war and practice, increase recycling of the grenade, increase the use of recycled material in the grenade, avoid use of electricity generated from fossil fuels, and consider replacement of hazardous substances both in the grenade and in production of the grenade. Data from this study can be reused in other LCAs on ammunition and form a starting point for building an LCA database for ammunition.

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1. Preface

This report presents the final results from a Life Cycle Assessment (LCA) of ammunition. The LCA study was a two-year project, mainly financed by the Swedish Armed Forces. The project concerns the use of life cycle assessment in the acquisition process. One of the goals of this case study is to demonstrate the feasibility of doing an LCA on a military product and illustrate the type of information an LCA can provide. The choice of the case study was done by the project team. The project also includes an analysis of how to integrate life cycle assessments in the acquisition process (Hochschorner and Finnveden, 2004). The study is made by personal working at the Swedish Defence Research Agency (FOI) and the Royal Institute of Technology (KTH), with contributions from the North Carolina State University. The latter was financed by the US Department of Defense. This cooperation was done within the framework of a research agreement between the Swedish Armed Forces and the US DoD.

A draft of this report was reviewed by Associate Professor Tomas Ekvall, Chalmers University of Technology, and discussed at a seminar. Many thanks to Tomas and others present at the seminar for useful comments. We are also grateful to all the people who has helped us find relevant information for the assessment.

This report has a number of appendices. This report as well as the appendices are available at www.infra.kth/fms. Kommentar: Här eller någon annanstans bör det stå vilka appendix som finns.

2. Procedure

One of the problems working with military material is secrecy. This presents a difficulty in finding data. In this study the chosen ammunition is an older type of ammunition, making it easier to find information. Both national and international data sources are used for this study.. A lot of information has been obtained from Bofors Defence AB, the manufacturer of the grenade (Bofors Defence 2002). This information comes from their standards and an LCA report they had prepared for a similar product (Edesgård and Eriksson, 1999). Information were also found in Jane's ammunition handbook (Gander and Cutshaw, 2000-2001) and an LCA report that Demex Consulting Engineers A/S (2000) made for Royal Ordnance PLC on an other type of munition.

We have performed a quantitative LCA using the computer program SimaPro 5.0 (www,pre.nl). The simulation was made as a comparison between two different life cycles; named "War" and "Total grenade". War is a scenario with shorter storage time and all the grenades are exploded in the environment. The war scenario includes impacts from the emissions when the grenades explode, but no direct impacts from the explosion on humans, society or environment. No parts are recycled or reused except in the production phases. This can be seen as a form of worst case. Total grenade corresponds to "normal" usage in Sweden. The grenades are maintained in storage until the end of the life cycle when these are destroyed, reused and recycled. About 5% of the grenades are "used" during practise in a shooting range, manoeuvre with reuse and recycling of all parts that can be reused and recycled. 100 grenades are used as a basis for the calculations. .

In parallel to the quantitative LCA has qualitative assessmement been done performed using a modified MECO assessment. The methodology is described below.

2.1 Life cycle assessment

Life cycle assessment (LCA) is the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout the life cycle. Life cycle includes mining of raw material, production, use and disposal of a product (i.e. from cradle to grave) (ISO, 1997). The term 'product' includes physical products as well as services. LCAs are often used as comparative studies. However, it is not the products that are compared, rather the function of the products.

The assessment is standardised in the ISO 14040- series (ISO, 1998; ISO, 2000a; ISO, 2000b; ISO, 1997), with a guide to the standards (Guinèe, 2003).

The analysis is performed in four phases, as described (according to Guinèe 2003) and illustrated below. During the process it can be necessary to go back to earlier phases to improve these.

- ***Definition of goal and scope:*** The goal of the study should be explained, the intended use of the results, the initiator of the study, the practitioner, stakeholders and intended users of the results should be specified. A scope definition establishes the main characteristics of an intended LCA study, for example a technical or a geographical study. The function, functional unit alternatives and reference flows should be defined in this phase.
- ***Inventory analysis:*** The product system is defined in the inventory analysis. The definition includes setting the system boundaries, designing the flow diagrams with unit processes, collecting data for each of these processes, performing allocation phases for multifunctional processes and completing the final calculations. The main result is an inventory table listing the quantified inputs and outputs to the environment associated with the functional unit, for example x kg carbon dioxide per studied product.
- ***Impact assessment:*** The results from the inventory analysis are further processed and interpreted in the Life Cycle Impact Assessment (LCIA). This phase includes classification, characterisation and the optional phases normalisation, grouping and weighting. A list of impact categories is defined that is used to classify the results from the inventory analysis, on a purely qualitative basis. The actual modelling results are calculated in characterisation phase. The optional normalisation serves to indicate the share of modelled results to a reference, e.g. a worldwide or regional total. The results can be grouped and weighted to include societal preferences of the various impact categories.
- ***Interpretation:*** The results from the analysis, all choices and assumptions made in the analysis are evaluated, in the interpretation, in terms of soundness and robustness. Conclusions are drawn and recommendations are made.

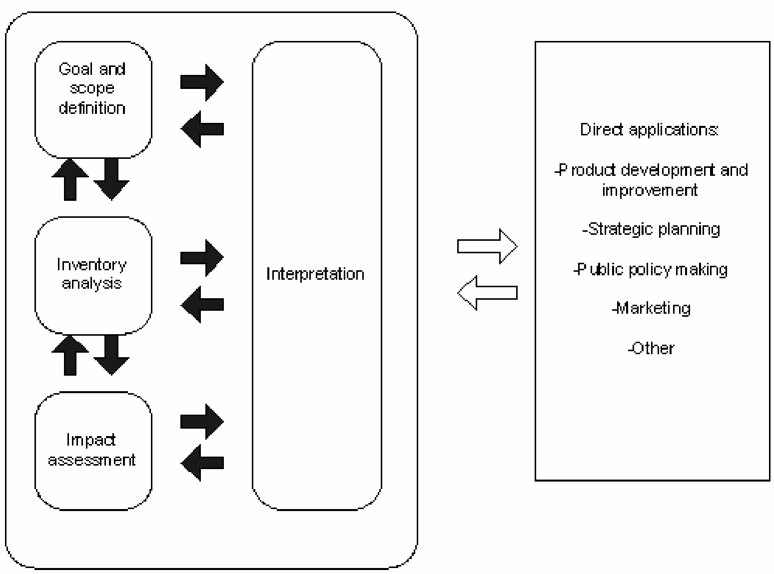

Figure 1. The framework for life cycle assessment, based on ISO 1997.

Since LCAs focus on products, use for product development and improvement is important, as well as use in purchasing.

It is not possible to quantify everything, so qualitative data and estimations are therefore necessary to create a comprehensive picture even in a quantitative LCA. It is also possible to consider quantitative information in a qualitative LCA, when such is easily accessible (Johansson et al., 2001)

2.2 The MECO principle

The MECO principle is a method for simplified LCA. The original MECO methodology is developed by The Danish Institute for Product Development and dk-TEKNIK in co-operation with a larger Danish project and described in (Pommer et al., 2001) and (Wenzel et al., 1997). The focus of the original method is the four areas Material, Energy, Chemicals and Others, thereby the name of the method. For a Swedish description of the method, see (Hochschorner et al., 2002). We have chosen this method after a review (Johansson et al., 2001) and evaluation (Hochschorner and Finnveden, 2003) of simplified LCAs. A modification of the MECO method for use in the Swedish defence has been made within this project and is described in full in (Hochschorner and Finnveden, 2004). The method can be used both as a pre-study and as a complement to a quantitative LCA, as concluded in (Hochschorner and Finnveden, 2003) . We have used the modified MECO method with the purpose to complement the quantitative LCA in this study. Below the methodology used is described.

The study focuses on the categories Chemicals and Others. Data of chemicals are the same cradle to gate data as in the quantitative LCA. This data is more comprehensive than normally included in a simplified LCA. Emissions that occur in the production of chemicals are not included. The result of the analysis will complement the quantitative LCA by more information on the substances' environmental and hazardous risks and by the possibility to include more qualitative information.

The chemicals are classified as type 1, 2, or 3 according to the environmental hazard level. The classification is made with help from the Swedish Defence Materiel Administration's (FMVs) list 'Restriktionslistan'(FMV, 2003). The purpose of Restriktionslistan is to help setting environmental requirements for procurement. The list consists of two parts, where the first part contains chemicals that shall not be included in products that FMV procure. The second part contains substances that should be avoided as far as possible. Chemicals are divided in the two parts by using their Risk-phrases (EU directives on marking of chemicals, (European Commision, 1967)) and their application in products. One example is lead that is included in both part 1 (as lead in electrical components, finishing, metals and fuels) and in part 2 (as lead in batteries and glue). (Lead has the Risk-phrases Repr.1; R61 Repr.3; R62 Xn; R20/22 R33 N; R50-53, for explanation see Appendix B). We have used the Risk-phrases and not the application of the chemicals to specify type 1-3 in our MECO assessment. To find Risk-phrases we have used the Swedish Klassificeringslistan or the N-Class Database (by the Nordic Council of Ministers). The criteria for the types are:

Type 1: Very problematic substances. These substances should, according to (FMV, 2003), not be included in products that FMV procure. Further valuation of these substances is needed, to find possible substitutes. Type 1 substances are substances with the Risk-phrases R26-28, 39, 45-46, 48-51, 53, 59-61 (as in part 1 in (FMV, 2003)).

Type 2: Problematic substances. Use of these substances should be avoided as far as possible, according to (FMV, 2003). Further evaluation of these substances is needed, to find possible substitutes. Type 2 substances are substances with Risk-phrases R20-25, 29, 31-38, 40-43, 48, 52, 54, 55-58, 62-68 (as in part 2 in (FMV, 2003)) and substances in the Swedish OBS-list (a list containing substances with serious environmental or health properties (Kemikalieinspektionen, 2000)). Substances that are difficult to assign a proper type, within reasonable time, should be classified as type 2.

Type 3: Less problematic substances. Use of type 3 substances is not regulated in Restriktionslistan. Type 3 substances are substances that do not fulfil the criteria for type 1 or 2.

Environmental impacts that do not fit into the category 'Chemicals' are included in the category 'Other'. This information can be both quantitative and qualitative and depends on the use of the method. We have included the following qualitative information in our MECO analyse of the Grenade:

- Components that are included in the product with unknown content, for example electronics
- The effect of use of the product in a war situation
- Noise

2.3 Calculation of LCI data

The backbone of a LCA is a Life Cycle Inventory. The objective of the inventory is to create a model of the product or activity identified during the goal and scope definition. The collection of data is the most time-consuming part in a LCA and involves a great deal of work to obtain faithful, transparent, and representative information about the many processes in a production system. Quite often, the practitioner faces the frustration of incomplete or missing information.

When performing a LCA of a military product, the amount of chemical substances involved in the supply chain increase geometrically in relation to the number of steps in the synthesis. The supply chains in this kind of production network can reach high degrees of complexity, and therefore, the information available about the chemical substances involved was limited.

The estimation of gate-to-gate life cycle information of chemical substances using chemical engineering process design techniques is becoming a feasible and a plausible LCI alternative (Gonzalez-Jimenez et al., 2000). It is a normal practice for manufacturing plants producing chemical substances to use design techniques for such plants, and so no major discrepancies with reality are expected (although not proven) when used for LCI. To further overcome the later concern, the transparency of the methodology and assumptions has become a priority.

In the CV-90, there are approximately 70 chemicals. The effort to generate LCI data was first given to chemical components with larger masses in the grenade for which LCI were not available. This led to a list of nine constituents for LCI development with a design based approach. Of these, five have been completed. The methodology developed for generating gate-to-gate data suitable for creating life cycle inventory information for chemical substances is presented schematically as stages in Figure 2 and described as follows:

1) Search and selection of the process. In this stage the process to be evaluated is chosen. It is important to ensure that the information is as updated as possible, and it is representative of the current industrial practice and of the region under study. The phases of this first stage could be described as follows:

> a) Investigation of the processes that have the significant industrial importance. Collect all the information regarding the process. Patents, articles, electronic and on-line databases, industrial bulletins, and direct industrial contacts are examples of the sources of information.
>
> b) Selection of the process to be used. This selection could be based on the amount, age, and scale of the information obtained, as well as on the process that is most common for the regional area under study. For the majority of chemicals there is economic competition that forces a similarity in chemical and energy efficiencies. Thus selecting any major process may be reasonably representative, given the modest level of precision needed in complex lci systems.

2) Definition of the process. This second stage determines and delimits the details of the process. We seek to define the mass flows in the process, the substances present in the system and the properties, and to identify the reactions involved and the conditions of all the operations. One decides on components when there is an opportunity of selecting these (e.g. solvents), and determines the unit operations used. The sequence of this stage is described as follows:

a) Description of the chemical reactions, including all names and structural formulae for reactants and products.

b) Identification of the conditions of temperature, pressure and composition under which each operation takes place.

c) Determination of the reaction conversion and separation efficiencies.
d) Elaboration of the flow diagram of the process with numbered process streams indicating the temperature and pressure conditions. The utilization of standard symbols is preferred (Sandler and Luckiewicz, 1987).

e) Search or estimation of the physical and chemical properties for all direct and indirect chemicals. A series of heuristics are used in all these steps to assure a reasonable uniformity across a large number of chemicals. In this way, the rules are not manufacturer-specific as currently found, but are more universal and thus somewhat less specific than at an actual plant. These rules have been an important streamlining technique in increasing the efficiency of LCI, without losing valuable chemical and energy information. This is a different form of streamlining from current LCI practices.

3) Mass Balance. In this stage, the calculations of mass for all inputs and outputs for the process are performed(referred to as a mass balance). All materials inputs and outputs will leave or enter the overall manufacturing system at 25 C and 1 atm., unless otherwise required specifically by the conditions of the process. This assures modules can be easily coupled without violating thermodynamic rules. The mass balance results are important from a LCI point of view since these determine the major contaminants produced in the process. In this stage:

a) A mass balance for a chosen basis of final product is performed. This establishes the general size of the process equipment needed in the design, normally 1,000kg/h. This design output is intermediate between commodity chemicals and specialized chemicals, since both are included in these LCI calculations (Sandler and Luckiewicz, 1987). It is also useful to enter in the process diagram every input and output for the overall process. It is also important that an industrial scale be used, so that realistic power and equipment size are used.

b) For estimating the chemical losses, the following are taken into consideration:
- Any inputs not in the product or marketable by-products are process emissions. Thus mass balances of overall processes are generally achieved. The process emission amounts are defined by variables such chemical reaction conversion, the feasibility of selling by-products, the efficiency of the separation processes selected, among others.
- Material Safety Data Sheets (MSDS) are used for each major process input. This information helps to determine the major impurities entering the system to later estimate, if possible, the fate of these in the manufacturing process.
- Fugitive losses: The percentages of fugitive losses are calculated based on the approximate overall amount of chemical present in the manufacturing system, not for each process separately and thus represent the overall manufacturing plant.
- Any water that is in contact with the other chemicals in the manufacturing process is referred to as contaminated water, and is accounted for separately.

4) Energy. The results from this stage will establish the amount of energy required from steam, fuel, electricity, and the energy losses of the process. In a further analysis these figures can be the basis for the calculation of the energy-related emissions (using any appropriate factors). Hence the goal is transparency. Important points to take into consideration are:

a) Heat of reaction and heat of dilution.

b) Sensible heat to reach reaction conditions

c) Energy for separation units, which will depend on the separation chosen.
The energy for every process is expressed in mega joules (MJ) per 1,000 kg of product in the final state.

d) Energy for materials transportation, such as pumps, compressors, fans, blowers, etc. The pressure needed is to transport the fluid a distance of 15m between individual processes, plus the pressure needed to move the fluid through the next unit process (pressure drop) (Woods, 1995).

e) For all distillations use a reflux ratio, R=1.3 (Mix, 1978), showing separately the reboiler energy requirement and the condenser. Reflux ratio is the mass of distillate that is recycled to the top of a distillation column divided by the mass of distillate removed as product.

f) Potential Energy Recovery. A table is prepared showing all heating requirements (positive) clearly labelled with the process name. Then all energy losses due to cooling (negative) are added, clearly labelled with the name of the process that is being cooled. Finally, an estimation of how much of this lost energy could be recovered is performed with the efficiency rules (Branan, 1994).

Using this methodology for the gate-to-gate life cycle inventories of specific chemicals found in the manufacturing of the CV-90 were calculated. The results are given below.

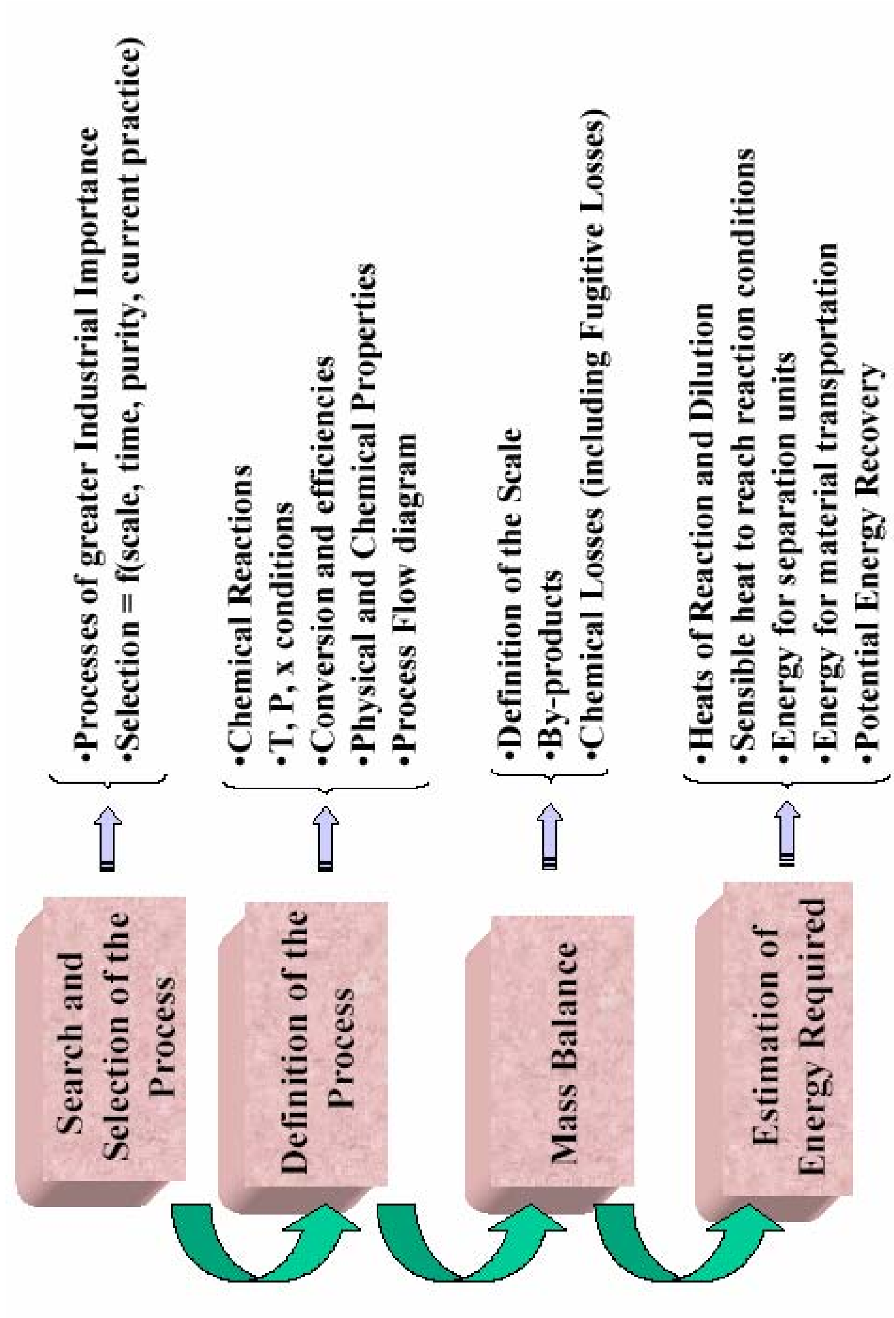

Figure 2. Methodology for creating gate-to-gate life cycle inventory information.

2.4 Overall methodological procedure

LCA is often described as an iterative process. The results presented in this report are results from several rounds of iterations using quantitative LCAs and the MECO method. The methodology for the quantitative LCA is largely based on the ISO standards (ISO, 1997, 1998, 1999, 2000 a,b) and the Dutch guide to the standards (Guinée, 2003). The detailed methodology is described below. For calculations, the software program SimaPro 5.0 is used (PRé, 2001) complemented with databases from IVAM and other datasources as described below. In order to find LCI data for some specific chemicals, the procedure described above is used.

The MECO method is used as a complement to the quantitative LCA. Since the Material and Energy parts of the MECO method are similar to the quantitative LCA, these were not used here. Instead only the Chemical and Other parts of the MECO method were used as described above.

3. Goal and scope definition

3.1 Goal definition

We have performed a comparative, descriptive assessment of 100 grenades used in peace and war like situations.

The goals of this study are:

- To identify aspect of the life cycle which have the largest impact on the environment.
- Suggest improvement possibilities for the life cycle of the grenade.
- To make a comparison between different approaches for waste management of the ammunition.
- To produce a demonstration case for obtaining a LCA on military material.

There are only a limited number of published case studies on LCAs of military materials. It is therefore of interest to produce such studies.

3.2 Scope definition

The scope of this study is, within practical limits, to do a quantitative LCA that includes all processes from cradle to grave for a grenade in the Swedish stockpile. In the study, data are taken from processes in the country where it is or was produced. If data from the producer country was unavailable, data were taken primarily from Sweden. In the case that there were no available data from Sweden any available data were used. Data was primarily taken from the original producer, in second hand from Ivam 4.0 or SimaPro databases. Ivam 4.0 is a database with the same format as the SimaPro database (www.ivam.nl). This grenade was produced mainly during the 1970s and the 1980s. If possible, data for the relevant time period were chosen, in practise data for current practise were often used.

Ideally an LCA includes all products and processes in the grenades life. However, this is not always possible in practise. Some of the things that have been excluded in the LCA are:

- Packing of the grenade and packing materials
- The manufacturing of capital goods
- Support material to capital goods, manufacturing processes and the use phase.

Allocation problems encountered are of two types: multi-output and open-loop recycling allocation problems. The latter type has been solved by system expansion as recommended by the ISO standard (ISO, 1998). Recycled materials are assumed to replace virgin materials. For some multi-output processes described below, all environmental impacts have been allocated to the main product. For many processes where data have been taken from databases, allocated data are used where different types of allocation approaches have been used.

Sometimes a distinction is made between consequential LCAs (which aim at modelling the consequences of a decsion) and descriptive or accounting LCAs, which aims at describing a product system (e.g. Guinee et al, 2002, Tillman, 2000). This study is a descriptive study. It is sometimes suggested that for descriptive studies, allocation is more adequate than system expansion (e.g. Tillman, 2000). This is however, not the position taken here. Instead the focus is on what system is to be described and modelled. Since the focus here is partly related to the comparison between different waste management strategies including recycling, it is appropiate to include also thefull recycling system, including alternative production methods, in the modelled system (c.f. Finnveden, 1999).

3.3 Functional unit

The functional unit is 100 grenades which are used in different ways in the two scenarios, a war scenario or in normal Swedish use. In the latter case, 95 % of the grenades are stored and then demilitarised and 5 % used in military practise. In the war scenario, all grenades are exploded and no parts recycled. Impacts included are emissions from the explosions. Impacts from the explosions on people, building and nature are not included in the quantitative LCA, only briefly commented in the qualitative assessment.

3.4 The LCA research Scientist

In this LCA project there is a mix of scientist involved. First there are two scientists, specialising in LCA; supported by a specialist on ammunition. In the project there is also cooperation with North Carolina State University who are experts on making LCI (life cycle inventory) on Chemicals.

4. Inventory analysis

4.1 Description of the grenade

An older type of ammunition has been chosen since the idea was that data would be easier to obtain. An older grenade does not differ much in construction and during the last 30 years not much has changed in the making on such a grenade. This mean that choosing an older grenade gives almost the same data as a newer one.
The grenade used is a very common grenade manufactured by Bofors since1975 which has been sold in about one million copies to over 30 nations. The model we used is called mark two and is from 1983. The grenade is a 40 mm grenade used by both land and sea weapons. It is constructed with heavy metal alloyed balls. The grenade is used primarily against air targets. In Sweden it has the name 40/48 KULSGR 90 and the international name is 40 mm L/70 PFHE mark two (Bofors Defence AB, 2002; Gander and Cutshaw, 2000-2001).

4.1 Grenade life cycle

The life cycle of the grenade and the sub parts is described below. It has been divided into several life stages: manufacturing, storage, use and demilitarization. Each of these has been combined for the total life cycle. We have chosen two different life cycles to compare. Those are “normal” usage of the grenade (total grenade scenario) and the war scenario (war scenario); differing in the end use of the grenades. War scenario doesn’t have a demilitarization part and the storage time is shortened. A larger transport and explosion of the grenade outdoors is also included in the war scenario simulating the actual driving the combat vehicle.

4.1.1 Manufacturing of the grenade

4.1.1.1 Cartridge

The grenade is cartridge-based ammunition, this mean that the grenade is mounted in a brass cartridge that contains some kind of propellant, in this case gunpowder. It has the appearance of an over sized rifle round.

The brass casing is made by Nammo in Finland and sold to Bofors who put it together (Edesgård and Eriksson, 1999). The process for doing the brass casing is called extrusion moulding. The case is extruded in three steps where the length of the case increased and the diameter and the wall thickness are decreased. The lengthening final stage is called first cutting of length and here excessive materials are cut off. After that the case base is pressed into shape. The last three steps are the conical pressing to match the size with the dimensions of the cartridge chamber, the machining of the base and the second cutting to length. The final finish of the cartridge is corrosion protection, the case is applied with a non-porous fine crystalline substance and then put in an oven at a high temperature (Demex et al., 2000).

The propellent in the cartridge is gunpowder, the gunpowder is a single base NC-powder (NitroCellulose). This gunpowder is made by Nexplo in Sweden. Gunpowder is produced by nitrating the cellulose and adding stabilisators and plastiziser. The process for making gun powder is a well documented process. Cellulose is first nitrated with nitric acid, resulting in nitrated cellulose with a high amount of water. The water is exchanged to ethanol with the use of a centrifuge. This product is then kneaded with an ether/ethanol mixture until a gel is formed. When the material is being kneaded stabilisatora and plastizisera are added. The gel is pressed through specific tools to make the desired shape of the final gun powder. The gun powder is now pre dried and then it is cut to appropriate size. The gun powder is then dried in a vacuum drier. The final stage is to treat its surface with graphite and other chemicals. The shaped gun powder is put into cotton bags and put into the cartridge (Bofors Defence AB, 2002).

4.1.1.2 Primer

At the bottom of the cartridge the primer is inserted. The function of the primer is to ignite the gunpowder in the cartridge. When the gunner wants to fire the grenade a button is pushed that sends an electric

current through a metal thread. The metal thread works like a light bulb filament, gets hot, and ignites the energetic materials in the primer (Bofors Defence AB, 2002).

The primer has three sub-parts: body, detonator and black powder. The body is made out of a brass casing just like the cartridge. It is shaped from a brass cylinder by turning. The detonator is the part that ignites when the metal thread gets hot. The detonator is about 1 mg of a mixture of antimony trisulphite, potassium perchlorate and zirconium. The detonator ignites the black powder which ignites the gun powder in the cartridge. The black powder is a mixture of charcoal, potassium nitrate and sulphur (Bofors Defence AB, 2002).

4.1.1.3 Pre Fragmented High Explosive (PFHE) Grenade
This is the part of the weapon system that does the damage. It is made out of several metal parts. In the middle there is a core (bursting charge) of energetic material in this case Octol.

Octol is made out of octogen and trinitrotoluene in a 70-30 mixture. Octogen is made from hexamine and a few other chemicals. Trinitrotoluene is toluene or ortho-toluene that is nitrated to trinitrotoluene with nitric acid. The Octol is melted into the grenade (Bofors Defence AB, 2002).

Around the bursting charge there is a steel skeleton, the steel is a special high fragmenting steel. This skeleton is made by turning a steel cylinder. The ball charge, consuming 600 heavy metal alloy balls (in tungsten) in a rubber matrix, is placed outside the steel cylinder. Outside this there is another steel casing that holds the ball charge in place also in the same steel as the skeleton. At the bottom there is a cap made of steel that is a safety measure for the grenade so the gunpowder can not accidentally ignite the grenade (Bofors Defence AB, 2002).

4.1.1.4 Fuse
At the top of the grenade there is a fuse. It is programmed to burst the grenade at the desired time. The fuse in this grenade is of proximity type and works according to the Doppler principle. This is the most complex component in the grenade. We have divided it into four sub-parts: electric unit, S/A device, fuse detonator and fuse body.

The electric unit is the sonar, it is made out of electronics and has a battery. A detonator is connected to the electronics, it is all cased in a noryl casing (plastic). The battery is a glass bottle, in the glass bottle there is a water solution of boric acid and flour boric acid, which is mixed under flight and gives a small amount of energy. The detonator in the electric unit ignites the fuse detonator. It is made of Graphite, lead azide, silver azide and Tetrazene in very small amounts (Bofors Defence AB, 2002).

The S/A device is a safety detail so the grenade can only burst after a specified time of flight. It is made in Switzerland and is in fact a small steel clock (Bofors Defence AB, 2002).

Fuse detonator is the energetic material that makes the octol in the PFHE shell to burst. This is first a small amount of trinitrophenylmethylnitramine (tetryl) and then a bigger booster of cyclotrimethylene trinitramine (hexogen) (Bofors Defence AB, 2002).

The S/A device and the fuse are fitted in an aluminium casing. This is turned out from an aluminium rod.

4.1.2 Storage
The main part of a grenades life is in storage. This could be from 10 to over 30 years. The value estimated for this LCA is 25 years. Storage facility has a climate and humidity control this mainly draws energy in the form of electricity (Fortifikationsverket, 2002).

4.1.3 Use of the grenade
The grenade that this study focuses on is used in combat vehicle 90 in the Swedish Armed Forces. The use of the grenade include some transportation (driving the CV 90) and firing the grenade which means that all materials in the grenade are spread into the environment.

Propellant and explosives in the grenade are combusted and the produced gases are assumed to be according to the bang box experiment (Wilcox, 1996).

4.1.4 Demilitarization

This is the end of the grenade life cycle. Here two possible demilitarization processes are used. The first is Open Detonation (OD), where a large amount of grenades are detonated in the open on a firing range in the country. This is the old way of doing demilitarization, but it is still used (Hägvall, 2002). The second method used is a Swedish method where all the materials in the grenade have been reused as much as it is possible. This means reclaiming explosive and propellants and reusing these and recycling all the material in the grenade such as steel and copper. Only a small amount of the explosive and propellant is not reused but are burned Sjöberg (2003). In this study, the latter type of demilitarisation is used. The demilitarisation is a sort of an ideal process, everything is recycled as much as possible.

One of the goals in this study is to do a comparison between different ends of life for grenades or rather waste management technologies. The scenario war is in fact comparable with OB/OD when nothing is collected for reuse recycling. This scenario can be compared to the opposite, that is the total grenade scenario were everything possible is recycled and reused actually simulating the Swedish way of recycling. The 5% in that scenario which are used for practise can actually be the amount of explosives, propellant and others that Sweden today don’t recycle. The comparison in this project is actually a comparison between old and new.

4.1.5 Process tree

Process trees for the chosen grenade and the two selected life cycles can be seen in . and . The complete process tree can be found in Appendix.

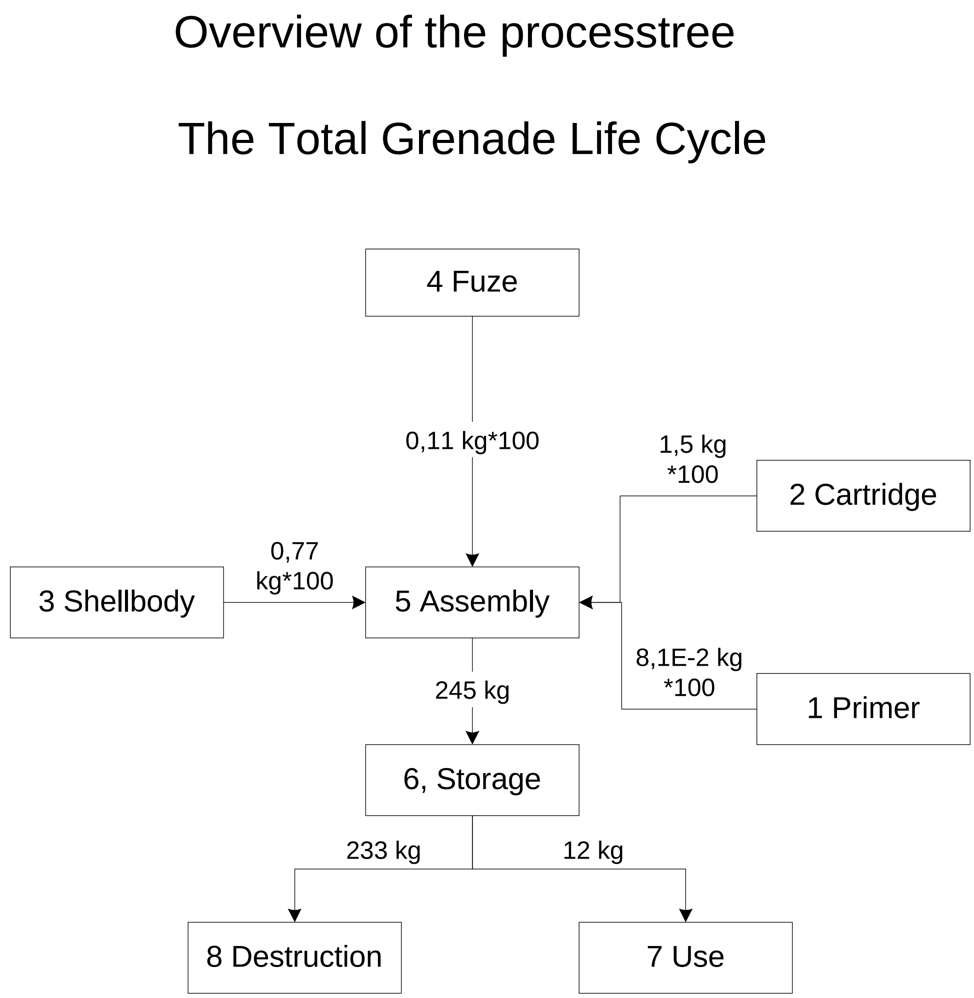

Figure 3, overview of the process tree for total grenade scenario

Overview of the processtree

The War Life Cycle

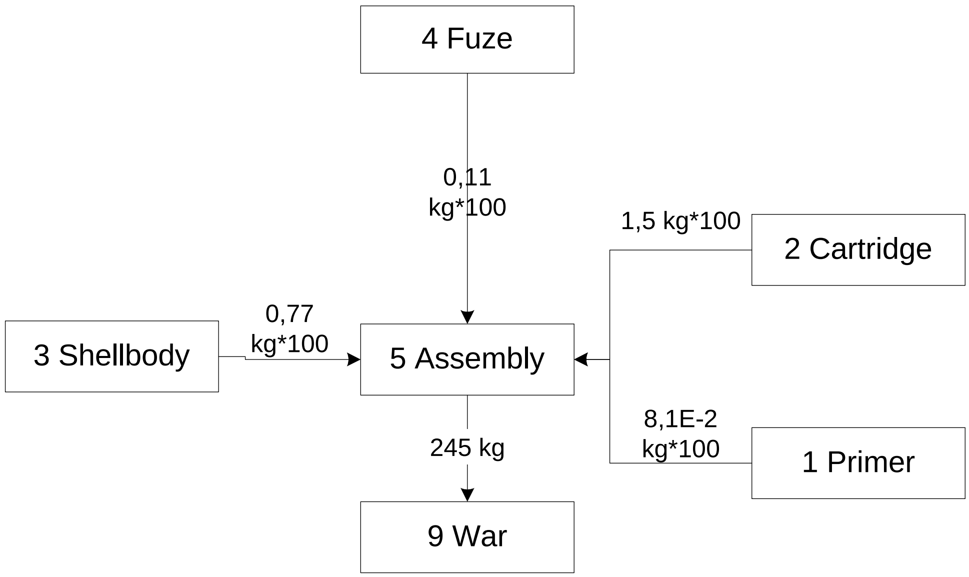

Figure 4, overview of the process tree for the war scenario

4.2 Economy-environment system boundary

The life cycle of the grenade is divided into four parts:

- **Assembly.** Production and assembly of the grenade.
- **Storage.** Storage of the grenade 25 years in a Swedish standard storage facility.
- **Use.** The use of the grenade in a practise application or a war situation, this includes transport to site and some driving until firing the grenade.
- **Destruction.** The disassembly of the grenade includes recycling of the parts that can go to recycling and burning of some energetic materials. Open burning is a process when energetic materials are burned in field with no pollution protection at all.

These four processes and the sub-processes are included in the assessment. We have excluded support equipment in all processes generated by us, for example maintaining, cutting fluid and so on. Excluded are also packaging materials and capital goods. Transports between all processes have been included, but almost all data are approximations.

4.3 Format and data categories

In this LCA we used SimaPro 5.0 and the format and data categories that are therein.

4.4 Data quality

The quality of the data differs a lot and is dependent on the source of data. The quality of the references used varies and will be discussed here.

Edesgård and Eriksson (1999) – This reference is a LCA produced as a master thesis, it is focused on the manufacturing of a similar grenade. It was made in close cooperation with Bofors Defence and its coverage of the “Bofors processes” is very good when it comes to energy usage and materials used. No chemical processes are included in the study and there is little information on processes outside Sweden. It was also made without the help of data bases and doesn’t really include all the aspects of a LCA.

Bofors environmental application (Nexplo Bofors AB, -2002) – This is the legal application that Bofors filed for their production according to Swedish environmental laws. It concentrates on the maximum production capability at this facility. Values from this reference were mostly used when no other source were available.

Bofors Defence standards (Bofors Defence AB, 2002) – This refers to the standards and drawings that Bofors Defence has provided for this research. The data were in the form of their standards and complete drawings of the grenade and all the parts it contains. Data provided directly from Bofors Defence also have this reference.

Wilcox et al. (1996) – This reference is a report from US army. It includes tests on open burning/ open detonation of munitions materials. This is used when explosives or propellant is burned or detonated. Validity is unknown but these are the best available data.

In addition, data with varying quality have been drawn from the Simapro data bases.

4.5 Data collection

Data was collected mostly by contacting the manufacturer in Sweden but also by using applications and other public documents that are filed by the companies according to the Swedish legislation. There are several substances without life cycle information; these can be seen in Table 1. Most of these constituents represent minor amounts compared to the weight of the grenade. There are however some exceptions: water, acetic acid anhydride (approx 0.5 kg which can be compared to the weight of the grenade which is 2.45 kg) and hexamine (approx 0.1 kg).

Table 1, Chemicals and energetic materials that are not included in the data-bases of Simapro.

Chemicals	Energetic materials
Acetic Acid anhydride	Tetrazene
Antimony trisulphide	Tetryl
Centralite I	
Diphenyl amine	
Ethanol	
Graphite	
HBF3	
Hexamine	
Lead acetate trihydrate	
Lead nitrate	
Potassium Nitrate	
Potassium Perchlorate	
Sodium bisulphite	
Sodium sulphite	
Water acidulated	
Water demineralised	
Zirconium type A	

4.6 Data sources

In Table 2 all materials and processes that have been inserted in SimaPro during this project can be seen with their reference.

Table 2, Substances and processes manufactured by this project in SimaPro

Name	Reference
Ammonium Nitrate	Calculated by the authors
Ball charge	Bofors, Edesgård & Eriksson
Battery electric unit	Bofors, Edesgård & Eriksson
Black powder	Estimation by the authors
Blank shell case	Bofors, Edesgård & Eriksson
Brass	Bofors, Edesgård & Eriksson
Cap	Bofors, Edesgård & Eriksson
Carbon Black 90	Pree
Cartridge case	Bofors, Edesgård & Eriksson
Detonator electric unit	Bofors, Edesgård & Eriksson
Diamylphatalat	Calculated by the authors
Disassembly of grenade	Estimation by the authors
Driving band blank	Bofors, Edesgård & Eriksson
Electric unit	Bofors, Edesgård & Eriksson
Fuse body	Bofors, Edesgård & Eriksson
Fuse detonator	Bofors, Edesgård & Eriksson
Gun powder	Bofors, Edesgård & Eriksson
H3BO3	Bofors, Edesgård & Eriksson
HBF3	Bofors, Edesgård & Eriksson
Hexogen	Estimation by the authors
Leadazide	Calculated by the authors
Leadoxide	Estimation by the authors
Nitrocelloluse	Bofors, Edesgård & Eriksson
Octogen	Estimation by the authors
Octol	Estimation by the authors
Primer body	Bofors, Edesgård & Eriksson
Primer detonator	Bofors, Edesgård & Eriksson
Recycling Acetic acid	Estimation by the authors
Recycling Aluminium	Estimation by the authors
Recycling Brass	Estimation by the authors
Recycling Copper	Estimation by the authors
Recycling HNO3	Estimation by the authors
Recycling Octol	Estimation by the authors
Recycling Steel	Estimation by the authors
Recycling Tungsten	Estimation by the authors
Reuse of cartridge	Estimation by the authors
S/A Device	Bofors, Edesgård & Eriksson
Shell body skeleton	Bofors, Edesgård & Eriksson
Silver azide	Calculated by the authors
Silver nitrate	Estimation by the authors
Sodium Azide	Estimation by the authors

Trotyl	Calculated by the authors
Tungstens balls	Bofors, Edesgård & Eriksson
Use War	Estimation by the authors
Waste explosive burning	Estimation by the authors
Water treatment	Estimation by the authors

Data for energy use are taken from the Buwal 250 database included in the Simapro databases in cases where country-specific data are used and from Ivam 4.0 in other cases.

4.8 Multifunctionallity and allocation

An allocation problem presents itself in the production of HMX (octogen) where RDX (hexogen) is simultaneously produced. In this case all environmental impacts have been allocated to the production of HMX.

In the case of recycling of different materials, it is assumed that recycled materials replace virgin materials. Se section 3.2.

4.9 Calculation of LCI data for some specific chemicals

Di n-amyl phthalic acid ester

This constituent is in the general chemical category of phthalates or plasticizers and is a low production volume product in this category. The Summary for di n-amyl phthalic acid ester is in Appendix. Sources used in the development of this LCI are Bergman et al. (1980); Ackerson (1969); Kirk and Othmer (1992) and Ullmann (2003). The LCI results for the gate to gate data are depicted in Table 3.

Table 3, Gate to gate life cycle inventory results for 1000 kg of

di n-amyl phthalic acid ester.

Raw material [kg]	Total* Diamyl phthalate GTG
Amyl alcohol	1.11E+03
Phthalic anhydride	3.75E+03

Energy [MJ]	Total* Diamyl phthalate GTG
Cooling water	9.46E+02
Diesel	4.40E+02
Electricity	5.86E-01
Potential energy recovery	-4.26E+02
Steam	1.05E+03
Total	2.01E+03

Air emissions [kg]	Total* Diamyl phthalate GTG
CH4	1.25E-01
CO	2.43E-01
CO2	1.17E+02
NMVOC	6.36E-01
NOx	9.00E-01
SOx	4.06E-01

Water emissions [kg]	Total* Diamyl phthalate GTG
Amyl alcohol	2.49E+01
BOD	8.51E-03
COD	2.61E-02
Diamyl phthalate	2.01E+00
Phthalic Anhydride	1.21E-02
TDS	4.33E-01

Solid wastes [kg]	Total* Diamyl phthalate GTG
Solid waste	2.54E-01

Ammonium Nitrate

This constituent is in the general chemical category of inorganic fertilizers and is a moderate production volume product in this category. The Summary for ammonium nitrate is in Appendix. Sources used in the development of this LCI are Chemical & Industrial Corp. (1961), DOE, Woods (1995), and Kirk and Othmer (1992). The gate-to-gate LCI results are depicted in Table 4.

Table 4, Gate-to-gate life cycle inventory results for 1000 kg ammonium nitrate

Raw material [kg]	Total* Ammonium nitrate GTG
Nitric acid	7.83E+02
Sulfuric acid	1.19E+01
Water including water for rxn	5.20E+02

Energy [MJ]	Total* Ammonium nitrate GTG
Cooling water	7.11E+02
Diesel	4.40E+02
Electricity	1.48E+00
Potential energy recovery	-2.83E+02
Steam	5.55E+02
Total	1.42E+03

Air emissions [kg]	Total* Ammonium nitrate GTG
CH4	7.45E-02
CO	2.16E-01
CO2	7.80E+01
Nitric acid	7.90E+00
NMVOC	4.39E-01
NOx	7.73E-01
SOx	2.37E-01

Water emissions [kg]	Total* Ammonium nitrate GTG

BOD	5.47E-03
COD	1.67E-02
Ammonium nitrate	1.01E-01
TDS	2.45E-01
Ammonium nitrate	1.01E-01
Waste water	5.15E+02

Solid wastes [kg]	Total* Ammonium nitrate GTG
Solid waste	1.72E-01

Trinitrotoluene

As an energetic constituent, TNT is in the general chemical category of explosive and is a moderate production volume product in this category. The Summary for trinitrotoluene is in Appendix 1. Sources used in the development of this LCI are Urbanski (1984) and Kirk and Othmer (1992). The gate-to-gate lci results are depicted in Table 5.

Table 5, Gate to gate life cycle inventory results for 1000 kg trinitrotoluene

Raw material [kg]	Total* TNT GTG
Nitric acid	1.11E+03
Sodium sulfite	1.20E+02
Sulfuric acid	2.00E+02
Toluene	4.67E+02
Water including water for rxn	3.75E+03

Energy [MJ]	Total* TNT GTG
Cooling water	2.20E+03
Diesel	4.40E+02
Electricity	1.19E+01
Potential energy recovery	-2.71E+02
Steam	1.23E+03
Total	3.61E+03

Air emissions [kg]	Total* TNT GTG
CH4	1.82E-01
CO	2.54E-01
CO2	1.33E+02
Nitric acid	7.68E+00
NMVOC	7.09E-01
NO2	3.90E-02
NOx	9.52E-01
Sodium hydroxide	2.72E-01
SOx	4.76E-01
Toluene	4.62E+00

Water emissions [kg]	Total* TNT GTG
BOD	9.93E-03

COD	3.73E-02
Dinitrotoluene	1.93E+01
NaOH	1.36E+01
Nitric Acid	1.69E+02
NO2	7.83E+00
Sodium sulfite	9.82E+01
Sulfuric acid	2.00E+02
TDS	5.64E-01
TNT	6.74E+01
TNT Isomers	1.94E-01
TNT Sulfonated	4.52E+01
Toluene	3.99E-01
Waste water	4.01E+03

Solid wastes [kg]	Total* TNT GTG
Solid waste	3.99E-01

Silver Azide
A smaller constituent of the CV-90 is silver azide, which is in the general chemical category of azides, but is a low production volume product in this category (sodium azide is the major product in this category). The Summary for silver azide is in Appendix. Sources used in the development of this LCI are Urbanski (1984); Meyer (1977) and Fair and Walker (1977). The LCI results for the gtg are in the Summary, given in Appendix.

Lead Azide
Another small constituent of the CV-90 is lead azide, which is in the general chemical category of azides, but is a low production volume product in this category (sodium azide is the major product in this category). The Summary for lead azide is in Appendix. The LCI results for the gtg are in the Summary, given in Appendix. These results are subsequently used in the overall CV-90 life cycle assessment as covered in the following chapters.

5. Impact assessment
In the Life Cycle Impact Assessment (LCIA) are the results from the inventory analysis further processed and interpreted in terms of environmental impacts and societal preferences (Guinée et al., 2002).

The impact assessment in our study includes a classification, characterisation and three different weighting methods, Ecotax 02, Ecoindicator-99 and EPS 2000. Each method is briefly described below. The selected impact categories and performance of characterisation are included in the description of the methods. Normalisation and grouping has not been included in our study.

5.1 Characterisation methods
The characterisation methods used in this study are baseline methods (Guinée et al., 2002) as included in the SimaPro 5.0 program except abiotic resources, where a method based on exergy content (Finnveden and Östlund, 1997) has been used.

5.2 Weighting methods

5.2.1 Ecotax 02
Ecotax 02 (Eldh, 2003) is an upgraded version of Ecotax 98 developed by (Johansson, 1999). Ecotax 98 is based on environmental taxes and fees in Sweden 1998. Ecotax 02 is updated with taxes and fees until the end of year 2002. The method links a tax or a fee to a relevant impact category. Even if a tax or a fee

is only expressed for one substance, it is possible to get a reference equivalent weight by making a characterisation factor conversion.

In the Ecotax methods are the baseline characterisation methods presented in Guinée et al.(2002) used for all selected impact categories except for abiotic resources. For abiotic resources a method based on exergy content (Finnveden and Östlund, 1997) has been used.

The method based on exergy content describes the use of energy and material resources as either consumption of exergy or production of entropy. Exergy can be described as a measure of available energy. The inputs should be natural resources as found in nature.

In Ecotax 02 are both characterisation methods and tax bases updated compared to Ecotax 98, for more detailed description, see Eldh (2003). Weighting factors used in Ecotax 02 are listed in Table 6, see below.

Table 6. Weighting factors for Ecotax derived from environmental taxes and fees in Sweden 2002. (Eldh, 2003, Björklund et al, 2003)

Intervention	Weighting factor	Tax or fee base
Extraction		
Fossil energy	0-0.15 SEK / MJ	Tax on fossil energy
Biotic energy	0-0.069 SEK/MJ	Tax on biotic energy
Emission		
CO2	0.63 SEK/kg	Tax on carbon content in fossil fuel
Ozone depleting substances	1200 SEK/kg	Fee for using prohibited ozone depleting substances
Nitrogen	12 SEK/kg	Tax on nitrogen content of fertiliser recalculated due to leakage of 15% (tax 1.80 SEK/kg)
HC	20-200 SEK/kg	Emission fee for air traffic
Sulphur	30 SEK/kg	Tax on sulphur content in fossil fuels
Toluene	17.65-36.07 SEK/kg	Tax differentiation on petrol qualities (unleaded petrol vs. alkylate petrol)
Cadmium	30 000 SEK/kg	Tax on content of cadmium exceeding 5 g/1000kg phosphorous in fertiliser
Pesticides / Copper	20 SEK/kg	Tax on active substance in pesticides

The weighting factors in Table 6 are combined with different impact categories in Table 7. Minimum and maximum values are used for some impact categories indicating uncertainties in the methods. The weights of reference in Table 7 indicate the value of the reference substance used in the different impact categories (Björklund et al., 2003; Eldh, 2003).

Table 7, Weights used in minimum and maximum combinations.

(Björklund et al, 2003, Eldh, 2003)

Impact category	Combination	Weighting factor	Reference of the characterisation method (eq)	Weight of reference
Abiotic resources	Min	0 SEK / MJ	MJ	0 SEK/MJ
	Max	0.15 SEK / MJ	MJ	0.15 SEK/MJ
Biotic resources	Min	0 SEK / MJ	MJ	0 SEK / MJ
	Max	0.069 SEK / MJ	MJ	0.069 SEK / MJ
Global warming	Min	0 SEK / kg CO_2	CO_2	0 SEK / kg CO_2
	Max	0.63 SEK / kg CO_2	CO_2	0.63 SEK/kg
Depletion of stratospheric ozone	Min/Max	1200 SEK / kg ozone depleting substance	CFC-11	1200 SEK/kg
Photochemical oxidation	Min	20 SEK / kg HC	C_2H_2	48 SEK/kg
	Max	200 SEK / kg HC	C_2H_2	480 SEK/kg
Acidification	Min/Max	30 SEK / kg Sulphur	1.2 SO_2	18 SEK/kg
Eutrophication	Min/Max	12 SEK / kg N	PO_4	28.57 SEK/kg
Fresh water aquatic ecotoxicity	Min	17.65 SEK/kg Toluene	1,4-dichlorobenzene emitted to freshwater	60.86 SEK/kg
	Max	36.07 SEK/kg Toluene		124.37 SEK/kg
Marine aquatic ecotoxicity	Min	20 SEK/kg Copper	1,4-dichlorobenzene emitted to seawater	$1.333*10^{-5}$ SEK/kg
	Max	20 SEK/kg Glyphosate		0.606 SEK/kg
Terrestrial ecotoxicity	Min/Max	30 000SEK/kg Cd	1,4-dichlorobenzene emitted to agr. Soil	176.47 SEK/kg
Human toxicity	Min/Max	30 000SEK/kg Cd	1,4-dichlorobenzene emitted to agr. Soil	1.50 SEK/kg

For further description of the method, see Johansson (1999), Finnveden et al. (2000) and Eldh (2003).

5.2.2 Ecoindicator-99

Ecoindicator is developed by PRé consultants in the Netherlands. The methodology is described in Goedkoop and Spriensma (2000). Three different versions of the method are developed, these are:

- **The egalitarian perspective:** A long term perspective is used. Even a minimum of scientific proof justifies inclusion.
- **The hierarchist perspective:** A balanced time perspective is used. Effects to be included are determined by consensus among scientists.
- **The individualist perspective**: A short time perspective is used and only proven effects are included.

In this LCA we have used the hierarchist perspective. In this perspective are substances included if there is consensus among scientists regarding the effect. For example, all carcinogenic substances in IARC

(International Agency for Research on Cancer) class 1, 2a and 2b are included, while class 3 has deliberately been excluded. In the hierarchist perspective, damages are assumed to be avoidable by good management. For instance the danger people have to flee from rising water levels is not included. In the case of fossil fuels the assumption is made that fossil fuels cannot easily be substituted. Oil and gas are to be replaced by shale, while coal is replaced by brown coal.

Weighting is performed for the three damage categories; Human health, Ecosystem quality and Resources. The impact categories and weighting factors are shown in Table 8 below.

Table 8. Impact categories and weighting factors used in

Ecoindicator 99 (SimaPro).

DALY= Disability Adjusted Life Years,

PDF=potentially disappeared fraction of species.

Impact category	Weighting factor	Unit
Human health Cancirogen	300	DALY
Human health Resp. org.	300	DALY
Human health Resp. inorg.	300	DALY
Human health Clim.change	300	DALY
Human health Radiation	300	DALY
Human health Ozone Layer	300	DALY
Ecosystem Quality Ecotox	400	PDF*m2yr
Ecosystem Quality Acid/Eutrophication	400	PDF*m2yr
Ecosystem Quality Land use	400	PDF*m2yr
Resources Minerals	300	MJ surplus energy
Resources Fossil fuels	300	MJ surplus energy

For more information, see Goedkoop and Spriensma (2000), information in the SimaPro program and www.pre.nl.

5.2.3 EPS (Environmental Priority Strategies)

The EPS method is developed within Centre for the environmental assessment of Products and Material systems (CPM) in Sweden. The methodology is described in Steen (1999). Weighting is made through valuation on the five damage categories human health, ecosystem production capacity, abiotic stock resource, biodiversity and also cultural and recreational values. Each damage category consists of impact categories. Weighting factors should represent the willingness to pay to avoid changes, and is calculated as environmental load units (ELU). More information can be found in Steen (1999).

5.3 Process contribution

A selection of the contribution from the different processes in the Grenade is shown in the tables below. The lists are structured with the largest total impact (summarised from the two different life cycles) first. The complete lists can be found in appendix.

Table 9, Results from SimaPro, a selection of process contribution from EcoTax 02 max, the complete table can be found in appendix.

Process	Unit	War	Total grenade
Total of all processes	Pt	11700000	787000
War	Pt	10800000	X
Aluminium (primary; Western Europe, 1989)	Pt	487000	487000
@MJel NL # (ETH3)	Pt	160000	133000
Electricity from coal B250	Pt	140000	142000
ECCS steel 20% scrap	Pt	84700	84700
Electr. Med. V. UCPTE	Pt	100000	434
Electricity from lignite B250	Pt	22700	22400
Electr. Low V. UCPTE	Pt	22900	20300
Electricity from oil B250	Pt	19200	20700
Incin. Electronics (sub) T	Pt	X	30700
MJel oil NL (ETH3)	Pt	14300	11100
Electricity from uranium B250	Pt	9240	10100
Synthesis gas	Pt	10300	8160
Electricity UCPTE Med. Voltage	Pt	X	18400
Use	Pt	X	18200
Western anode	Pt	4710	4710
Waste explosive burning	Pt	81,9	7690
@Diesel precomb # (ETH3)	Pt	9540	-3290
Octogen	Pt	4980	953
MJel NL # (ETH3)	Pt	2350	2250
@Truck 40t # (ETH3)	Pt	2200	2200
@Truck 16t # (ETH3)	Pt	2160	2160
@MJth industrial # (ETH3)	Pt	2820	367
Electronics (average)	Pt	1270	1270
Transport rail (ETH3)	Pt	2100	79,7
EPDM rubber ETH T	Pt	1060	1060
Heat diesel B250	Pt	822	1190
Electricity from gas B250	Pt	961	961
Electricity from hydropwr B250	Pt	809	881
Trotyl	Pt	1300	356
Copper (primary)	Pt	1550	6,71
HNO3 (100%)	Pt	701	670
Copper conc (30%)	Pt	1210	5,27
Nitrocellulose	Pt	568	568
Energy Asia I	Pt	1020	50,6

The results from the EcoTax 02 max show that War is the most important process. It contributes to 92% of the war scenario and is almost 14 times larger than the total grenade scenario. Primary aluminium production is also a large contributor in both war and total grenade. Resource use, emissions of metals and use of non renewable energy sources contribute to the most important processes for the total grenade.

Table 10, Results from SimaPro, a selection of process contribution from EcoTax 02 min, the complete table can be found in appendix.

Process	Unit	War	Total grenade
Total of all processes	Pt	2820000	40000
War	Pt	2790000	X
Incin. Electronics (sub) T	Pt	X	26000
Synthesis gas	Pt	9060	7170
Octogen	Pt	4750	909
Use	Pt	X	4760
ECCS steel 20% scrap	Pt	2070	2070
@MJel NL # (ETH3)	Pt	1680	1390
Electricity from oil B250	Pt	857	922
Trotyl	Pt	1290	354
Electricity from coal B250	Pt	798	811
HNO3 (100%)	Pt	696	665
Electr. Med. V. UCPTE	Pt	1290	5,59
Nitrocellulose	Pt	568	568
Aluminium (primary; Western Europe, 1989)	Pt	453	453
Western anode	Pt	418	418
@Diesel precomb # (ETH3)	Pt	1230	-426
Copper (primary)	Pt	793	3,44
Waste explosive burning	Pt	7,11	667
Electr. Low V. UCPTE	Pt	300	266
Diamylphatalate	Pt	240	240
Acetic acid	Pt	392	64,4
@Truck 16t # (ETH3)	Pt	215	215
MJel oil NL (ETH3)	Pt	221	172
Ammonia	Pt	199	188
Energy Asia I	Pt	356	17,7

The results from the EcoTax 02 min show that War is the most important process of all even. It contributes to 99% of the war scenario and is 70 times larger that the total grenade life cycle. The largest impact in the Total grenade scenario is the incineration of electronics, where emission of mercury to air dominates the result. It is not clear if these data are representative also for the electronics present in the grenade. We can also see synthetic gas as an important factor in both scenarios.

Table 11, Results from SimaPro, a selection of process contribution from Eco-indicator 99, the complete table can be found in appendix.

Process	Unit	War	Total grenade
Total of all processes	Pt	16000	275
War	Pt	15400	x
Copper conc (30%)	Pt	169	0,733
ECCS steel 20% scrap	Pt	72,2	72,2
Electricity from oil B250	Pt	63,2	67,9
@MJel NL # (ETH3)	Pt	42,7	35,4
Electricity from coal B250	Pt	28,8	29,3
Copper (primary)	Pt	52,1	0,226
Synthesis gas	Pt	28,2	22,3
Energy Asia I	Pt	15,4	0,764
Heat diesel B250	Pt	5,91	8,59
Electricity from uranium B250	Pt	6,89	7,54
Use	Pt	X	14,1
Electricity from gas B250	Pt	5,86	5,86
HNO3 (100%)	Pt	5,53	5,28
Ammonia	Pt	5,2	4,91
Electr. Med. V. UCPTE	Pt	8,63	0,0374
Waste explosive burning	Pt	0,0864	8,11
@MJth industrial # (ETH3)	Pt	7,2	0,937
@Natural gas precomb # (ETH3)	Pt	4,19	3,19
@Diesel precomb # (ETH3)	Pt	10,2	-3,52
Electronics (average)	Pt	2,78	2,78
Electr. Low V. UCPTE	Pt	2,12	1,87
MJth heavy fuel oil	Pt	3,37	0,175
Limestone IVAM	Pt	4,23	-0,853
@Truck 16t # (ETH3)	Pt	1,52	1,52
Electricity from lignite B250	Pt	1,27	1,25

The result from Eco- indicator shows that war stands for 96% of the war scenario. The war process has more than 50 times of the impact of the whole total grenade life cycle. It can also bee seen that energy and metals are large contributors to the total impacts. The effect of the reuse/recycling of copper can be seen as the impact of copper in the war scenario is much larger than in the total grenade scenario.

Table 12, Results from SimaPro, a selection of process contribution from EPS 2000, the complete table can be found in appendix.

Process	Unit	War	Total grenade
Total of all processes	Pt	36300	6010
Copper conc (30%)	Pt	26800	116
HNO3 (100%)	Pt	5050	4820
Zinc conc	Pt	1610	80,8
@MJel NL # (ETH3)	Pt	794	659
ECCS steel 20% scrap	Pt	354	354
Mercury (primary)	Pt	187	186
Electr. Med. V. UCPTE	Pt	346	1,5
Copper (primary)	Pt	319	1,39
Electronics (average)	Pt	111	111
Synthesis gas	Pt	113	89,1
Electricity from oil B250	Pt	90,4	97,3
Electr. Low V. UCPTE	Pt	91,7	81,2
Tungsten I	Pt	134	6,62
Electricity from uranium B250	Pt	63,8	69,8
Chromium (primary)	Pt	52,5	52,5
Energy Asia I	Pt	74,4	3,68
Electricity from coal B250	Pt	32,6	33,1
Ammonia	Pt	33,5	31,6
Electricity UCPTE Med. Voltage	Pt	X	64
Western anode	Pt	31,6	31,6
Aluminium (primary; Western Europe, 1989)	Pt	26,6	26,6
Electricity from gas B250	Pt	26	26
@MJth industrial # (ETH3)	Pt	41,9	5,45
MJth gas energy	Pt	17,2	15,6
Leadoxide	Pt	15,7	15,7
@Diesel precomb # (ETH3)	Pt	46,5	-16
@Natural gas precomb # (ETH3)	Pt	17,2	13,1
Waste explosive burning	Pt	0,311	29,2

The results from the EPS 2000, shows a different view than the others. Here war is not the biggest impact and it comes first on the 30th place with 27,1 Pt in impact, which can be seen in the complete table in appendix. This is because this method focuses mainly on resource depletion, which is evident when we see that most of the impacts originate from resources including both non renewable energy and metals. (After the study was completed it was noted in the review process that the impact from the copper production is overestimated by approx 30 %. This is because different concentrations of copper in the copper ore were assumed in the inventory analysis and in the EPS weighting system. This does however not change any conclusions of this study).

5.4 Results from the characterisation

Results from the characterisation in the three methods are shown below. There is no difference between Ecotax min and max, since the same characterisation methods are used. Non-quantified but relevant environmental aspects are included in the MECO-assessment, see section 5.6 below.

Table 13, Results from SimaPro characterization of EcoTax 02 (RT)

Impact category	Unit	War	Total grenade
Resources exergy energy	MJ	82700	59200
Resources exergy biotic	MJ	14000	14300
Global warming GWP100	Kg CO2 eq	4000	2960
Ozone layer depletion	Kg CFC-11 eq	0,00046	0,000429
Photochemical oxidation max	Kg C2H2	4,16	1,4
Acidification	Kg SO2 eq	53,3	19
Eutrophication	Kg PO4--- eq	58,7	43,4
Fresh water ecotox.	Kg 1,4-DB eq	42800	141
Marine aquatic ecotox.	Kg 1,4-DB eq	10100000	1190000
Terrestial ecotox.	Kg 1,4-DB eq	1020	153
Human tox.	Kg 1,4-DB eq	20400	2470

The result from the EcoTax 02 method shows that the largest difference between the two cycles is in fresh water ecotoxicology where the war cycle is about 300 times the value of total grenade cycle. For human tox and terrestrial ecotoxicological impacts, the difference is approximately one order of magnitude.

Table 14, Result from SimaPro characterization of Eco-indicator 99

Impact category	Unit	War	Total grenade
HH Carcinogen.	DALY	0,00631	0,00654
HH Resp. org.	DALY	9,17E-06	3,8E-06
HH Resp. inorg.	DALY	0,00349	0,000725
HH Clim.change	DALY	0,000853	0,000633
HH Radiation	DALY	2,89E-09	2,89E-09
HH Ozone layer	DALY	4,2E-07	4,01E-07
EQ Ecotox.	PDF*m2yr	1980000	3120
EQ Acid/Eutroph	PDF*m2yr	81	39,7
EQ Land-use	PDF*m2yr	-0,448	0,683
R Minerals	MJ surpl	4840	54,6
R Fossil fuels	MJ surpl	3910	2570

When the characterisation methods of the Eco-indicator 99 are used, the results indicate large differences in several areas between the war and the total grenade scenarios. The two largest differences are for EQ ecotoxicology where there is a factor of 600 difference (war has the largest impact) and resources minerals with a factor 90 difference (war has the largest impact). As for the land use category with a below zero value we have not concentrated on this issue, and the result of that category is questionable.

Table 15, Results from SimaPro characterization of EPS 2000

Impact category	Unit	War	Total grenade
Life Expectancy	PersonYr	0,0048	0,00107
Severe Morbidity	PersonYr	0,000868	0,000538
Morbidity	PersonYr	0,00306	0,00209
Severe Nuisance	PersonYr	0,0197	0,00279
Nuisance	PersonYr	0,248	0,0586
Crop Growth Capacity	Kg	12,9	9,28
Wood Growth Capacity	Kg	-151	-105
Fish and Meat production	Kg	-0,39	-0,342
Soil Acidification	H+ eq.	64,4	19,1
Prod. Cap. Irrigation Water	Kg	76000	46400
Prod. Cap. Drinking water	Kg	76000	46400
Depletion of reserves	ELU/kg	33000	4270
Species Extinction	[-]	4,27E-11	3,79E-11

The result in the EPS 2000 doesn't show the large differences between the two scenarios compared to the previous methods. Differences can be seen in the areas of severe nuisance and species extinction but they are "only" a factor seven in difference. This indicates that this method mainly gets its impacts from processes that are similar for the two cycles.

5.5 Results from the weighting

Results from the weighting with the three methods are shown below.

Table 16, Results from SimaPro weighting of EcoTax 02 max

Impact category	Unit	War	Total grenade
Total	Pt	11700000	787000
Resources exergy energy	Pt	14000	10000
Ressources exergy biotic	Pt	963	990
Global warming GWP100	Pt	2520	1860
Ozone layer depletion	Pt	0,553	0,515
Photochemical oxidation max	Pt	2000	671
Acidification	Pt	959	342
Eutrofering	Pt	634	497
Fresh water ecotox.	Pt	5320000	17500
Marine aquatic ecotox.	Pt	6110000	724000
Terrestial ecotox.	Pt	180000	27000
Human tox.	Pt	30600	3710

The result from the weighting using the EcoTax max method shows that most of the impact from the war cycle is distributed on two categories: fresh water ecotoxicology and marine aquatic ecotoxicology with almost half on both. In the total grenade cycle marine aquatic ecotoxicology stands for the major part of the impact. It can also bee seen that terrestrial ecotoxicology has a prominent place in both cycle.

Table 17, Results from SimaPro weighting of EcoTax 02 min

Impact category	Unit	War	Total grenade
Total	Pt	2820000	40000
Resources exergy energy	Pt	0	0
Ressources exergy biotic	Pt	0	0
Global warming GWP100	Pt	2520	1860
Ozone layer depletion	Pt	0,553	0,515
Photochemical oxidation max	Pt	195	62,8
Acidification	Pt	959	342
Eutrofering	Pt	634	497
Fresh water ecotox.	Pt	2600000	6630
Marine aquatic ecotox.	Pt	134	15,9
Terrestial ecotox.	Pt	180000	27000
Human tox.	Pt	30600	3710

The result from the EcoTax min method shows that almost all the impact in the war cycle originates from the fresh water ecotoxicology. Terrestrial ecotoxicology also has a small part of it. The total grenade cycle on the other hand show most impact from terrestrial ecotoxicology and a clearly smaller from freshwater ecotoxicology, the opposite from the War cycle.

Table 18, Results from SimaPro weighting of Eco-indicator 99

Impact category	Unit	War	Total grenade
Total	Pt	16000	275
HH Carcinogen.	Pt	123	128
HH Resp. org.	Pt	0,179	0,0743
HH Resp. inorg.	Pt	68,2	14,2
HH Clim.change	Pt	16,7	12,4
HH Radiation	Pt	5,65E-05	5,65E-05
HH Ozone layer	Pt	0,0082	0,00782
EQ Ecotox.	Pt	15500	24,3
EQ Acid/Eutroph	Pt	6,32	3,1
EQ Land-use	Pt	-0,0349	0,0532
R Minerals	Pt	173	1,95
R Fossil fuels	Pt	140	91,7

The results from the eco-indicator method show that almost all of the war cycles impacts originate from the EQ ecotoxicology category. The other impact categories have only minor influence on the total result in the war scenario. The total grenade cycle has large impacts from human health carcinogen and resources fossil fuel while the Eq ecotoxicology only comes in third place.

Table 19, Results from SimaPro weighting of EPS 2000

Damage category	Unit	War	Total grenade
Total	Pt	36300	6010
Human Health	Pt	747	199
Ecosystem Production Capacity	Pt	2500	1530
Abiotic Stock Resource	Pt	33000	4270
Biodiversity	Pt	4,7	4,17

The result from the EPS only has four damage categories, both scenarios have largely the same distribution, with the abiotic stock resource category as the largest.

5.6 Contribution from emissions and resource depletion

In SimaPro it is possible to see which emission or resource depletion that has the largest effect in each method. The results are presented in this section. They are presented for Eco-indicator and EPS as single

score (the biggest contributor for the whole method) and for EcoTax max and min for each impact category both as characterised and weighted values. Focus is on the war scenario.

Table 20, Material effects on Eco Indicator, Single score 1% cut off with focus on war

No	Substance	Compartment	Unit	War	Total grenade
	Total of all compartments		Pt	16000	275
	Remaining substances		Pt	258	140
1	copper (ore)	Raw	Pt	169	1,26
2	metallic ions	Water	Pt	116	121
3	Copper	Soil	Pt	8470	14
4	Zinc	Soil	Pt	6970	x

In Table 20 are the results from the Eco Indicator method presented. It can be seen that substances that stand for than one percent of the total impact in the war scenario are one resource and 3 emissions, all are metals. The remaining impacts in total grenade scenario are about half of the total impact.

Table 21, Material effects on EPS, Single score 1% cut off with focus on war

No	Substance	Compartment	Unit	War	Total grenade
	Total of all compartments		Pt	36300	6010
	Remaining substances		Pt	1940	483
1	Water	Raw	Pt	926	559
2	water (surface, for cooling)	Raw	Pt	1580	1510
3	Zinc (ore)	Raw	Pt	1610	74,1
4	platinum (in ore)	Raw	Pt	3330	3180
5	copper (ore)	Raw	Pt	26900	200

The results from the EPS method is presented in Table 21, Material effects on EPS, Single score 1% . Here it is clear that the 5 most important materials in the war scenario that cause 99% of the impact are all resources.

5.6.1 Abiotic resources as exergy use

Table 22, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracterisation factors (MJ/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						MJ	59200	82700
	Remaining substances						MJ	115	4550
1	uranium (in ore)	Raw	g	67,1	66,3	504	MJ	33800	33400
2	natural gas (35,0 MJ/m3) ETH	Raw	m3	144	214	35	MJ	5050	7490
3	copper (ore)	Raw	m3	85	11400	0,63	MJ	53,6	7210
4	coal (30.3 MJ/kg)	Raw	kg	189	189	30,3	MJ	5720	5720
5	natural gas (vol)	Raw	kg	104	143	38,9	MJ	4060	5550
6	coal ETH	Raw	kg	118	150	27	MJ	3180	4060
7	crude oil ETH	Raw	kg	108	96	42	MJ	4520	4030
8	crude oil (42,6 MJ/kg) ETH	Raw	kg	9,24	86,4	42,6	MJ	394	3680
9	coal (18 MJ/kg) ETH	Raw	kg	110	188	18	MJ	1970	3390
10	crude oil IDEMAT	Raw	kg	2,31	46,6	42	MJ	96,9	1960
11	zinc (ore)	Raw	kg	32,5	708	1,9	MJ	61,8	1340
12	natural gas ETH	Raw	m3	31,9	29,7	38,9	MJ	1240	1160
13	coal (29.3 MJ/kg)	Raw	kg	-37,2	-29,1	29,3	MJ	-1090	-853

Table 22 shows characterisation results for abiotic resources using the exergy method. It can be seen that non renewable fuels have a large effect on this impact category. Also copper has a significant effect. The negative value for the remaining substances in the Total Grenade scenario is caused by the recycling of materials. Uranium stands for the largest impact ~1/4 in the war cycle and ~1/3 in the total grenade cycle.

5.6.2 Resources Exergy Biotic

Table 23, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracteri sation factors (MJ/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						MJ	14300	14000
	Remaining substances						MJ	-333	22,3
1	pot. energy hydropower	Raw	MWh	3,55	3,26	3600	MJ	12800	11700
2	wood	Raw	kg	92,7	93,6	19	MJ	1760	1780
3	energy from hydro power	Raw	MJ	132	417	1	MJ	132	417

that hydro power stands for the largest part of the impact. Wood has a smaller part but still substantial.

5.6.3 Global Warming (GWP)

Table 24, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracteri sation factors (Kg CO2 eq/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						kg CO2 eq	2960	4000
	Remaining substances						kg CO2 eq	0,671	1,07
1	CO2 (fossil)	Air	tn.lg	1,22	1,82	1000	kg CO2 eq	1240	1850
2	N2O	Air	kg	3,23	3,42	310	kg CO2 eq	1000	1060
3	CO2	Air	kg	629	981	1	kg CO2 eq	629	981
4	methane	Air	kg	4,14	5,25	21	kg CO2 eq	87	110

The results in show that emissions of N_2O and CO_2 stand for the largest contribution to Global Warming.

5.6.4 Ozon layer depletion

Table 25, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracterisation factors (Kg CFC11 eq/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						kg CFC-11	0,000429	0,00046
	Remaining substances						kg CFC-11	0,0000208	0,00000362
1	HALON-1301	Air	mg	29,4	32,1	1,20E-05	kg CFC-11	0,000352	0,000385
2	CFC-21	Air	mg	45,8	58,5	1,00E-06	kg CFC-11	0,0000458	0,0000585
3	CFC-114	Air	mg	12,3	15,7	8,50E-07	kg CFC-11	0,0000105	0,0000134

The results in show that the most part of the impact comes from the emission of halon 1301.

5.6.5 Photochemical oxidation max

Table 26, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracterisation factors (Kg C2H2/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						kg C2H2	1,4	4,16
	Remaining substances						kg C2H2	0,162	0,158
1	SO2	Air	oz	10,6	933	1,37E-03	kg C2H2	0,0144	1,27
2	CxHy	Air	oz	31	119	6,13E-03	kg C2H2	0,194	0,74
3	non methane VOC	Air	kg	1,18	1,28	2,20E-01	kg C2H2	0,259	0,281
4	SOx (as SO2)	Air	kg	5,02	5,13	4,80E-02	kg C2H2	0,241	0,246
5	acetone	Air	oz	16,9	84	2,68E-03	kg C2H2	0,0451	0,224
6	CxHy (non methane)	Air	g	300	915	2,20E-04	kg C2H2	0,0661	0,201
7	CO	Air	kg	4,03	7,11	2,70E-02	kg C2H2	0,109	0,192
8	cyclohexanone	Air	g	103	510	2,90E-04	kg C2H2	0,0307	0,153
9	non-methane hydrocarbons	Air	g	160	602	2,20E-04	kg C2H2	0,0351	0,133
10	acetic acid	Air	oz	9,71	48,1	2,76E-03	kg C2H2	0,0267	0,132
11	NOx	Air	kg	2,41	4,03	2,80E-02	kg C2H2	0,0674	0,113
12	sulphur	Air	kg	1,86	1,97	4,80E-02	kg C2H2	0,0891	0,0944
13	alkanes	Air	g	15,4	177	5,00E-04	kg C2H2	0,00768	0,0884
14	hydrocarbons	Air	g	30,8	302	2,20E-04	kg C2H2	0,00678	0,0665
15	VOC	Air	g	300	300	2,20E-04	kg C2H2	0,066	0,066
16	SOx	Air	oz	2,15	43,4	1,37E-03	kg C2H2	0,00292	0,0591
17	NO	Air	g	56,3	134	-4,27E-04	kg C2H2	-0,024	-0,057

The result in for the impact category Photochemical oxidation shows that the emission of C_xH_y stands for the largest impact in both cycles. In the war cycle there is also a large impact from the emission of SO_2 although that contribution is negative in the total grenade cycle.

5.6.6 Acidification

Table 27, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracterisation factors (Kg SO2 eq/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						kg SO2 eq	19	53,3
	Remaining substances						kg SO2 eq	0,289	0,639
1	SO2	Air	oz	10,6	933	0,034199999	kg SO2 eq	0,36	31,7
2	HNO3	Air	kg	14	14,2	0,51	kg SO2 eq	7,16	7,25
3	SOx (as SO2)	Air	kg	5,02	5,13	1,2	kg SO2 eq	6,02	6,16
4	sulphur	Air	kg	1,86	1,97	1,2	kg SO2 eq	2,23	2,36
5	NOx	Air	kg	2,41	4,03	0,5	kg SO2 eq	1,2	2,02
6	SOx	Air	oz	2,15	43,4	0,034200487	kg SO2 eq	0,073	1,48
7	NOx (as NO2)	Air	kg	1,96	1,7	0,5	kg SO2 eq	0,979	0,852
8	ammonia	Air	g	424	500	1,60E-03	kg SO2 eq	0,679	0,8

show the characterisation results for acidification which indicate that for the war cycle about half the impact comes from SO_2 emissions and another third comes from the emissions of nitric acid, sulphur and SO_x. As for the total grenade it is the combination of emissions from nitric acid, sulphur and SO_x that stands for more than 75% of the total impact.

5.6.7 Eutrophication

Table 28, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracterisation factors (Kg PO4 eq/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						kg PO4--- eq	17,4	22,2
	Remaining substances						kg PO4--- eq	0,588	0,881
1	HNO3	Water	kg	140	141	0,1	kg PO4--- eq	14	14,1
2	ammonium nitrate	Water	kg	2,48	12,3	0,43	kg PO4--- eq	1,07	5,3
3	HNO3	Air	kg	14	14,2	0,1	kg PO4--- eq	1,4	1,42
4	NOx	Air	kg	2,41	4,03	0,13	kg PO4--- eq	0,313	0,524

shows the characterisation results for eutrophication. For the war scenario, the emission of TOC to water stands for more than 50% of the impact and emission of nitric acid to water stands for more than 20%. The total grenade cycle shows similar result with more than 50% from TOC and 30% from nitric acid.

5.6.8 Fresh Water ecotox

Table 29, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracterisation factors (Kg 1,4-DB eq/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						kg 1,4-DB eq	141	42800
	Remaining substances						kg 1,4-DB eq	70,3	51,8
1	copper	Soil	lb	0,265	160	267,6194524	kg 1,4-DB eq	70,8	42700

The results in for Fresh water ecotox impacts shows that for the war scenario are emissions of copper to soil the most important and also in the total grenade scenario this is important (~50%).

5.6.9 Marine Aquatic Ecotox.

Table 30, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracterisation factors (Kg 1,4-DB eq/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						kg 1,4-DB eq	1190000	10100000
	Remaining substances						kg 1,4-DB eq	112000	149000
1	copper	Soil	lb	0,265	160	5,44E+04	kg 1,4-DB eq	14400	8690000
2	HF	Air	g	26	30,5	4,10E+04	kg 1,4-DB eq	1070000	1250000

show results for marine aquatic ecotox impacts. Also in this case have emissions of copper to soil the largest impact in the war scenario. In the total grenade scenario has the emission of hydrogen fluoride the largest impact.

5.6.10 Terrestial ecotox.

Table 31, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracterisation factors (Kg 1,4-DB eq/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						kg 1,4-DB eq	153	1020
	Remaining substances						kg 1,4-DB eq	151	6,26
1	copper	Soil	lb	0,265	160	6,350292091	kg 1,4-DB eq	1,68	1010

show characterisation results for terrestrial ecotoxicity. Again, for the war scenario is the emission of copper to soil the most important. For the total grenade scenario has emission of mercury to air the largest impact (this is not possible to see in this table but can be seen in the complete table in appendix).

5.6.11 Human tox.

Table 32, Impact indicator EcoTax 02, 1% cut off with focus on war

No	Substance	Compartment	Unit (Amount)	Total grenade	War	Caracterisation factors (Kg 1,4-DB eq/nn)	Unit (Impact indicator)	Total grenade	War
	Total of all compartments						kg 1,4-DB eq	2470	20400
	Remaining substances						kg 1,4-DB eq	687	907
1	copper	Soil	lb	0,265	160	42,63767547	kg 1,4-DB eq	11,3	6810
2	CxHy	Air	oz	31	119	5,41E+01	kg 1,4-DB eq	1670	6390
3	CxHy (non methane)	Air	g	300	915	1,90E+00	kg 1,4-DB eq	571	1740
4	octogen	Water	g	135	658	1,80E+00	kg 1,4-DB eq	243	1180
5	non-methane hydrocarbons	Air	g	160	602	1,90E+00	kg 1,4-DB eq	303	1140
6	acetone	Water	g	110	544	1,80E+00	kg 1,4-DB eq	197	980
7	cyclohexanone	Water	g	103	510	1,80E+00	kg 1,4-DB eq	185	919
8	hydrocarbons	Air	g	30,8	302	1,90E+00	kg 1,4-DB eq	58,5	574
9	Trotyl	Water	g	80,9	257	1,80E+00	kg 1,4-DB eq	146	462
10	TNT-Sulfonated	Water	g	44,7	163	1,80E+00	kg 1,4-DB eq	80,4	293
11	aromatics	Air	g	5,7	114	1,90E+00	kg 1,4-DB eq	10,8	217
12	PAH's	Air	g	-2,97	-2,1	5,70E+02	kg 1,4-DB eq	-1690	-1200

The characterisation results for human toxicity in show that for the war cycle there are two emissions that stands for the major part of the impact, C_xH_y to air and copper to soil. In the total grenade it is only one emission that stands for the major part of the impact and that is C_xH_y to air.

5.7 Undefined substances

When the inventory list is compared to the weighting and characterisation methods, some of the substances are not included in the two methods. These are called undefined substances.

We have used the rules for undefined substances described in. (Eldh, 2003)
Almost all undefined substances can be divided into one of the following three types: a synonym, an almost equivalent substance, or an unknown substance. In Ecotax 02 the following guidelines to handle undefined substances are used: (Eldh, 2003)

- For synonyms: Use the same characterisation factor for all synonyms, for example Cu and Copper.
- For similar substances: Use the same characterisation factor for similar substances, for example PM10 and coal dust.
- Groups of substances are replaced with the value of the single substance, e.g. Phenols are set to the value of Phenol.
- Hydrocarbons are set to the value of Benzene, except those containing chloro-, these have been assigned the value of 1,4-dichlorobenzene.

Among the undefined substances are different solid emissions. The total contribution to solid emission for the grenade, according to the four methods, is described in
Table 33.

Table 33, Solid emissions that are not included in the weighting

Total grenade	**War**
429,32 kg and 2E-5 m3 nuclear waste	12287,34 kg and 5,5E-5 m3 nuclear waste

The 10 largest amounts of solid waste, according to the methods, are shown in the tables below.

Table 34, The ten largest solid waste types in the total grenade scenario, generated from Ecotax 02 max.

Solid waste type	Unit	Amount
final waste (inert)	Kg	230
Slag	Kg	61,6
Steinkohleberge-Dep	Kg	48,8
mineral waste (mining)	Kg	38,5
Tailings	Kg	15,4
Waste in inert landfill	Kg	10,6
steel scrap	Kg	10,4
Abfaelle-Inertst.dep	Kg	9,44
dust, break-out	Kg	9,43
toxic waste	Kg	8,95

Table 35, The ten largest solid waste types

in the war scenario, generated from Ecotax 02 max.

Solid waste type	Unit	Amount
Tailings	Kg	11700
final waste (inert)	Kg	248
Slag	Kg	124
Steinkohleberge-Dep	Kg	59,2
mineral waste (mining)	Kg	38,5
toxic waste	Kg	27
fly ash	Kg	16,5
Abfaelle-Inertst.dep	Kg	12,3
Waste in inert landfill	Kg	10,6
dust, break-out	Kg	9,43

The largest amounts of solid waste consist of final waste, tailings and slag.

Lists for all undefined substances are included in the appendix. There are also substances that could not be followed to the cradle, these are listed in section 4,5 Data collection.

5.8 Results from the MECO analysis

This MECO assessment is used as a complement to the quantitative LCA, and therefore are only the dimensions Chemicals and Other are included, as described in section 2.2. All classified chemicals are included in Appendix B. The appendix shows the different materials and the substances these are produced from (for example: Brass consists of Zinc and Copper) and the different amounts of the substances. Electricity used and emissions that occur when producing or using the Grenade have not been included.

The following five tables shows all substances included in one grenade, divided by their types; Type 1 (), type 2 (), type 3 () and chemicals that could not be assigned a proper type (and).

The comparison of chemicals in the life cycles Total Grenade and War cannot be made, since the results are identical in this approach.

Table 36, Chemicals in the grenade that are classified as type 1.

[1]Mining gas is assumed to be natural gas.

[2] R-phrases from Kemiska ämnen 8.0 Prevent

25 substances are classified as type 1.

Resource	CAS- number	R-phrase	The OBS-list	Type
Ammonia	7664-41-7	R10 T; R23 C; R34 N; R50	Yes	1
Benzene	71-43-2	F; R11 Carc.1; R45 T; R48/23/24/25	Yes	1
Chlorine	7782-50-5	T; R23 Xi; R36/37/38 N; R50	Yes	1
Cobalt	7440-48-4	R42/43 R53	Yes	1
Crude oil	8002-05-09	Carc.2; R45	Yes	1
Diphenyl amine	122-39-4	T; R23/24/25 R33 N; R50-53	Yes	1
Heavy fuel oil	92045-14-2	Carc.2; R45	No	1
Lead	7439-92-1	Repr. 1; R61 Repr. 3; R62 Xn; R20/22 R33 N; R50-53	Yes	1
Lead acetate trihydrate	6080-56-4	Repr.1; R61 Repr.3; R62 Xn; R20/22 R33 N; R50-53	Yes	1
Lead azide	13424-46-9	*E*; *R3* Repr1; R61 Repr3; R62 Xn; R20/22 R33 N; R50-53	Yes	1
Lead oxide	1317-36-8	Repr.1; R61 Repr.3; R62 Xn; R20/22 R33 N; R50-53	Yes	1
Mercury	7439-97-6	T; R23 R33 N; R50-53	Yes	1
Methane	74-82-8	F+; R12	No	1
Mining gas[1]	64741-48-6	Carc.2; R45 Xn;R65	no	1
Naphtha	8030-30-6	Canc2; R45 Xn; R65	No	1
Natural gas	64741-48-6	Carc.2; R45 Xn;R65	No	1
Octogen[2]	2691-41-0	R3, R21, R50	No	1
Pentane	109-66-0	*F+*; *R12* Xn; R65 R66 R67 N; R51-53	No	1
Petroleum gas	92045-80-2	F+; R12 Carc.2; R45	No	1
Pitch	61789-60-4	Canc2; R45	No	1
Silver	7440-22-4	Repr.1; R61 Repr.3; R62 Xn; R20/22 R33 N; R50-53	No	1
Silver nitrate	7761-88-8	C; R34 N; R50-53	Yes	1
Sodium azide	26628-22-8	T+; R28 R32 N; R50-53	No	1
Trotyl (TNT)	118-96-7	E;R2 T; R23/24/25 R33 N;R51-53	No	1
Uranium	7440-61-1	T+; R26/28 R33 R53	No	1

Table 37, Chemicals in the grenade that are classified as type 2.

[1] R-phrases from Kemiska ämnen 8.0 Prevent
24 substances are classified as type 2.

Resource	CAS- number	R-phrase	The OBS-list	Type
Acetic acid	64-19-7	*R10* C; R35	No	2
Chromium	7440-47-3	Missing	Yes	2
Copper	7440-50-8	Missing	Yes	2
Formaldehyde	50-00-0	Carc.3; R40 T; R23/24/25 C; R34 R43	Yes	2
H2SO4	7664-93-9	C; R35	No	2
Hexamine	100-97-0	F; R11 R42/43	Yes	2
Hexogen[1]	121-82-4	R25, R3	No	2
HNO3	7697-37-2	O; R8 C; R35	No	2
Methanol	67-56-1	F; R11 T; R23/24/25-39/23/24/25	No	2
NaOH	1310-73-2	C; R35	No	2
Nickel	7440-02-0	Carc.3; R40 R43	Yes	2
Phthalic acid anhydride	85-44-9	Xn; R22 Xi; R37/38-41 R42/43	Yes	2
Potassium perchlorate	7778-74-7	O;R9 Xn;R22	No	2
P-xylene	106-42-3	R10 Xn;R20/21 Xi; R38	No	2
Soda	497-19-8	Xi; R36	No	2
Sodium	7440-23-5	*F*; *R14/15* C; R34	No	2
Tetryl	479-45-8	*E*; *R2* T; R23/24/25 R33	No	2
Xylene	1330-20-7	*R10* Xn; R20/21 Xi; R38	No	2
Zinc	7440-66-6	F; R15-17	Yes	2
Diesel	68334-30-5	Carc.3; R40	No	2
Brass (CuZn30)	Missing	Missing	Yes	2
Toluene	108-88-3	F; R11 Xn; R20	No	2
Silver azide	13863-88-2	Missing	Yes	2
Nitric acid (HNO3)	7697-37-2	O; R8 C; R35	No	2

Table 38, Chemicals in the grenade that are classified as type 3.

Water and wood has been classified as type 3, although we could not find R-phrases for them.
10 substances are classified as type 3.

Resource	CAS- number	R-phrase	TheOBS-list	Type
Air	132259-10-0	Missing	No	3
Aluminium	7429-90-5	F; R15-17	No	3
Ethanol	64-17-5	F; R11	No	3
H2	1333-74-0	F+; R12	No	3
Magnesium (in ore)	7439-95-4	*F*; *R15-17*	No	3
Nitrocellulose	9004-70-0	E; R3 R1	No	3
Oxygen	7782-44-7	O;R8	No	3
Water	7732-18-5	Missing	No	3
Wood	Missing	Missing	No	3
Zirconium	7440-67-7	F; R15-17	No	3

Table 39, Chemicals in the grenade with known CAS numbers and unknown R-phrases.

These chemicals are classified as type 2, since information is missing to assign them a proper type.

This list contains 53 substances.
[1]Gas from oil production is assumed to be Synthetic natural gas.

Resource	CAS- number	R-phrase	TheOBS-list	Type
ABS a	9003-56-9	Missing	No	2
Al2O3	1344-28-1	Missing	No	2
AlF3	7784-18-1	Missing	No	2
Ammonium nitrate	6484-52-2	Missing	No	2
Baryte	13462-86-7	Missing	No	2
Bauxite	1318-16-7	Missing	No	2
Bentonite	1302-78-9	Missing	No	2
Calcium sulphate	7778-18-9	Missing	No	2
Carbon black	1333-86-4	Missing	No	2
Cellulose	9004-34-6	Missing	No	2
Chalk	13397-25-6	Missing	No	2
Charcoal	16291-96-6	Missing	No	2
Clay	1302-78-9	Missing	No	2
Coal	7440-44-0	Missing	No	2
Coke	65996-77-2	Missing	No	2
Diamyl phthalate	131-18-0	Missing	No	2
Dolomite	16389-88-1	Missing	No	2
EPDM	9010-79-1	Missing	No	2
Feldspar	68476-25-5	Missing	No	2
Ferromanganese	12604-53-4	Missing	No	2
Fluorspar	14542-23-5	Missing	No	2
Gas from oil production[1]	8006-14-2	Missing	No	2
Glass	65997-17-3	Missing	No	2
Graphite	7782-42-5	Missing	No	2
H3BO3	10043-35-3	Missing	No	2
Iron	7439-89-6	Missing	No	2
KCl	7447-40-7	Missing	No	2
Limestone	1317-65-3	Missing	No	2
Manganese	7439-96-5	Missing	No	2
N2 (liquid)	7727-37-9	Missing	No	2
N2O	10024-97-2	Missing	No	2
NaCl	7647-14-5	Missing	No	2
Nitrogen	7727-37-9	Missing	No	2
Olivine (group minerals)	1317-71-1	Missing	No	2
Palladium	7440-05-03	Missing	No	2
Phosphate (as P2O5)	68891-72-5	Missing	No	2
Platinum	7440-06-04	Missing	No	2
Potassium nitrate	7757-79-1	Missing	No	2
Potassium sulphate	7778-80-5	Missing	No	2
PVC B250	9002-86-2	Missing	No	2
Quartz sand	14808-60-7	Missing	No	2
Rhenium	7440-15-5	Missing	No	2
Rhodium	7440-16-6	Missing	No	2
Rutile	1317-80-2	Missing	No	2
Sodium sulphite	7757-83-7	Missing	No	2
Steel	12696-99-0	Missing	No	2
Steel	68467-81-2	Missing	No	2
Sulphur	7704-34-9	Missing	No	2
Syntesis gas	8006-14-2	Missing	No	2
Talc	14807-96-6	Missing	No	2
Tetrazene	14097-21-3	Missing	No	2
Tin	7440-31-5	Missing	No	2
Tungsten (Wolfram)	7440-33-7	Missing	No	2

Table 40, Chemicals in the grenade with unknown CAS numbers and R-phrases.

These chemicals are classified as type 2, since information is missing to assign them a proper type. This list contains 38 substances.

Resource	CAS- number	R-phrase	The OBS-list	Type
Acetic acid anhydride	Missing	Missing	No	2
Additions	Missing	Missing	No	2
Additives	Missing	Missing	No	2
Antimony trisulphide	Missing	Missing	No	2
Auxiliary materials	Missing	Missing	No	2
Black powder	Missing	Missing	No	2
Centralite I	Missing	Missing	No	2
Degreasing agent	Missing	Missing	No	2
Ferrochrome HC	Missing	Missing	No	2
Float agent	Missing	Missing	No	2
Granite	Missing	Missing	No	2
Gravel	Missing	Missing	No	2
HCl	Missing	Missing	No	2
Lignite	Missing	Missing	No	2
Marl	Missing	Missing	No	2
Molybdene	Missing	Missing	No	2
Octol	Missing	Missing	No	2
Pellets	Missing	Missing	No	2
Pig Iron	Missing	Missing	No	2
Quicklime	Missing	Missing	No	2
River sand	Missing	Missing	No	2
Rock Salt	Missing	Missing	No	2
Sand	Missing	Missing	No	2
Scrap	Missing	Missing	No	2
Sec anode	Missing	Missing	No	2
Shale	Missing	Missing	No	2
Stainless Steel	Missing	Missing	No	2
Western anode	Missing	Missing	No	2
Acids	Missing	Missing	No	2
Alloys	Missing	Missing	No	2
DMT (terephthalic acid)	Missing	Missing	No	2
Cathode	Missing	Missing	No	2
Clay minerals	Missing	Missing	No	2
HBF3	Missing	Missing	No	2
Na2B4O7*xH2O	Missing	Missing	No	2
Rolling oil	Missing	Missing	No	2
Sinter	Missing	Missing	No	2

In a total we have found 150 different substances in the grenade, 25 are classified as type 1, 115 as type 2 and 10 as type 3. 91 substances of the 115 substances classified as type 2are lacking information for assigning a proper type. We have found CAS-numbers for 53 of these 91 substances, but no risk-phrases for any of them.

The following information is included in the dimension other:

- We have no data on the electronics in the fuse; we have used the data for “electronics average” in the SimaPro database.
- The use of a grenade in a war situation implies disaster and destruction of humans, society and environment.
- The use of the grenade in a practice situation implies noise to the surroundings.
- Impacts on land occur during many activities in the life cycle of a grenade, both in a peace and war situation. For example: mining of raw materials, energy generation, transports to production, storage house, practice areas and not the least during use in a war situation.

5.9 Sensitivity analysis

A sensitivity analysis is performed by using four different weighting methods.

6. Discussion, Conclusion and Interpretation

According to a decision made by the Swedish government in 1998 the Swedish Defence and the Defence Materiel Administration (FMV) must take environmental consideration in to all phases of the acquisition of defence materiel. One of the major difficulties when taking environmental consideration into purchasing decisions is the lack of reliable information about the environmental characteristics of the product or service (OECD, 2000). Different tools developed for environmental consideration in product development can contribute with some knowledge and help to set up feasible requirements on a product. LCAs are useful since these focuses on the product. Very few life cycle assessments of munitions have been made. Hopefully this study can serve as a demonstration case for future LCAs.

It is, of-course, difficult to analyse products in a war situation, not the least ammunitions. The destruction munition can achieve in a war or warlike situation has not been included in this study. The war situation focuses on the use of the grenades, where no waste treatment is performed.

To compare such use of the grenade with the use that is normal in Sweden today gives a good knowledge on the environmental impact that occurs during the life cycles and which aspects have the largest impact. This sort of knowledge is valuable when procuring and developing new ammunition, and also when using or taking care of existing ammunition.

In the original MECO method the analysis is focused on the four categories Material, Energy, Chemicals and Others. In this study we used the method mainly as a complement to the quantitative LCA and used data from the quantitative LCA in the MECO study. We found that the categories Material and Energy can be excluded, since the quantitative LCA generates more information on both these categories. On the other hand, the MECO method generates complementary information in the two other categories. It generates more information on hazardous substances, by using Risk-phrases, in the category Chemicals. In the category Other qualitative aspects that are not included in the quantitative LCA can be included. By being complementary to the quantitative LCA, results from the MECO method should also be used in the evaluation of the whole LCA study.

The four goals in our study are stated in section 3.1. The results from the study are interpreted according to these goals:

Goal: To identify which aspect of the Life cycle has the largest impact on the environment?
<u>The war scenario:</u>
In the war scenario, the most environmental hazardous process is the actual war impacts according to Ecotax 02 max, Ecotax 02 min (RT) and Eco-indicator 99. In the war process, the grenade is transported by truck and train and detonated outdoors. The emissions and transport data can be found in Appendix.

According to EPS 2000 it is the mining of copper ore (copper conc 30%) in the grenade that has the largest environmental impact. These data are from IVAM 4,0. Copper is used in the Brass in the Cartridge case, in the PFHE Shell and the Primer. Copper is classified as type 2 according to the MECO assessment.

The total grenade scenario:

The most important processes in the total grenade scenario from an environmental point are according to the different impact assessment methods:

- **Ecotax 02 max:** Primary aluminium production in Western Europe, this is used in the fuze body. Data are from IVAM 4,0. Aluminium is classified as type 3 according to the MECO assessment.
- **Ecotax 02 min (RT):** Incineration of electronics. Electronics are used in the Fuze. We do not know what the actual electronics in the grenade contain, so we have used average data on electronics that are included in the database IVAM 4,0 in SimaPro. Since electronics have a large impact in the total grenade scenario, it is a good idea to evaluate these further.
- **Eco-indicator 99:** The four processes that are most environmental hazardous are ECCS Steel, consisting of 20% steel scrap (26% of the total contribution), Electricity from oil (25%), Electricity from the Netherlands (13%) and Electricity from coal (11%). The ECCS Steel is used in the Shell body Skeleton, the Cap and the Blank Shell Case. Electricity from oil is used in the processing of Ammonium nitrate that is used in Hexogen and Octogen.
- **EPS 2000:** Production of HNO3. HNO3 is used in mining of copper and production of Octol in the PFHE Shell. It is also used for production of Lead azide in the Fuze, Aluminium in the Fuze body, Hexogen in the Fuze, Brass in the Cartridge case and Nitrocellulose in the Cartridge. HNO3 is classified as type 2 according to the MECO assessment.

The most hazardous substances according to the MECO method are classified as type 1 and shown in table in section 5.8. Some of these substances are not directly included in the grenade, but are used in production of the chemicals. Chemicals directly included in the grenade and of type 1 are: Diphenyl amine, Lead azide and Lead oxide. The bursting charge in the grenade is Octol, which consists of Octogen and Trotyl, both classified as type 1. A lot of type 1 substances are energy carriers, for example crude oil, heavy fuel oil and petroleum gas. Other chemicals that are directly included in the grenade are classified as type 2 or 3. Type 2 chemicals that are classified using the R-phrases or because these are included in the OBS-list and are directly included in the grenade are: Copper, Hexogen, Tetryl and Brass. A lot of chemicals have been classified as type 2, since these can not be assigned another type.

Goal: Suggest improvement possibilities for the life cycle of the grenade.

According to the results from the quantitative LCA and the MECO method we suggest the following improvement strategies: Change the shell in the grenade, decrease the use in war and practice, increase recycling of the grenade, increase the use of recycled material in the grenade, avoid use of electricity generated from fossil fuels, and consider replacement of hazardous substances both in the grenade and in production of the grenade. All substances of type 1 and 2, according to the MECO assessment, shall be analysed further, since the use of these should be restricted according to the Restriktiosnlistan (FMV, 2003).

Goal: To make a comparison between different end of life scenarios.

The war scenario can be compared to open detonation/open burning. When comparing the open detonation/open burning (in the war scenario) with recycling (in the Total Grenade) we found that the war scenario has higher environmental impact on almost every impact category in the different methods, see section 5,4 Results from the characterisation.

The total weighted value is according to all weighting methods larger for open burning/war scenario than from the recycling/Total grenade, see section 5,5 Results from the weighting. The weighted values in the different categories are larger for all categories in all methods, except for Eco-indicator 99 where the weighted value for the impact category Carcinogens is 4% larger for the Total grenade. The solid emissions from the grenade used in the war scenario are about 3 times larger than in the Total Grenade scenario.

The comparison of end of life scenarios has not been included in the analysis with the MECO method.

Goal: To make a demonstration case about doing a LCA on military material.

This goal is fulfilled by this study. Data from this study can be reused in other LCAs on ammunition and form a starting point for building an LCA database for ammunition.

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